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Stern Billy
Making paper
from Montana's
straw : a guide
to making...

Making Paper From Montana's Straw

A Guide to Making Straw Pulp a Reality

by

Billy Stern
Pulp and Paper Strategist

made possible by the
Native Forest Network Inc.

and

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Montana Agriculture Development Council
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EXECUTIVE SUMMARY

SUMMARY OF FINDINGS

The main objective of "Making Paper from Montana's Straw" is to benefit Montana's agricultural community by creating a new market for straw. The study investigates the practical aspects and economics of using Montana's excess straw to make paper products, sets a foundation for further research and development, and outlines a plan that facilitates this new market's start-up. As it develops, this new market would create new jobs and new investment opportunities.

The report begins by gathering information on the availability for straw in Montana, with a careful consideration of the possible impacts residue removal could have on soils. Under some conditions impacts exist from excess residue removal, including erosion, nutrient and moisture loss and reduced yield. Conversely, with some tillage practices, leaving too much reside can also reduce yield. Many growers already remove or burn a portion or their straw. The conclusion is that 25% removal of straw would have negligible short- or long-term effects in most areas, and higher collection rates may be possible. Nevertheless, soil conditions and crop yields should be closely monitored, and further studies pursued.

Recent estimates show over 7,000,000 acres planted in wheat or barley in Montana. Other estimates suggest each acre produces an average of 3000 lb of straw. Combined, these figures show over 10 million tons of straw are produced annually in Montana. At 25% removal, 2.5 million tons of straw may be gathered as a raw material for the use in various products, including paper. This is sufficient to fully supply 50 small mills using 50,000 tons per year (tpy) or presuming a 50% yield from pulping, more than 1.5 mills the size of the Smurfit-Stone mill in Frenchtown.

Next the study considers the systems and costs for purchasing, collecting, storing, transporting, and processing straw. Estimates show that straw could be delivered to a mill for between $65-135/ton, depending on various factors, with the distance to the mill causing the greatest cost differential. A mill placed close to the source of the straw is considered most likely to be profitable. However, shipping straw to Frenchtown is still a possibility because of the benefits of the existing effluent treatment and chemical recovery systems at the facility.

Due to the characteristics of straw fiber, straw pulp has good smoothness, opacity and stiffness, but is lacking in tear and burst strength. Pulp make from straw is best suited for corrugated medium, newsprint, printing and writing papers, and linerboard. Usually paper products are not made from 100% straw pulp, but are mixed with recycled or wood pulps, and could be mixed with other nonwoods.

Existing straw pulping technologies are explaining and examined at length, and some potential new pulping processes are considered in brief. The Kraft pulping process normally used to pulp wood is not the best suited for straw. Potassium, caustic soda, and stream-based pulping processes are all more suitable and could be used at a new mill, or incorporated into a straw pulping line at the Frenchtown mill.

No final recommendation is made for a pulping process or company to design a mill, as different processes are more suitable for different products. Instead, a guide is presented to facilitate the selection of a process and of a mill location, by presenting the important issues that need to be addressed in a step-by-step approach. In addition, a set of criteria are developed as a guide to making sure the type of straw mill chosen is acceptable to the community and in meet both existing state and federal environmental laws, and possibly tightened regulations in the future.

In addition to the main body of the report , it also includes a number of other resources presented in the appendixes:

- A bibliography of straw pulping studies and articles, and of articles related to the impacts on soils of removing residues;
- A lists of individuals and companies who might bid on designing a straw pulp mill;
- A lists of facilities currently using or experimenting with straw pulping;
- A lists of groups and individuals possibly interested in investing in a straw mill;
- A lists of important technical expects and promoters of straw pulping and nonwood paper.

This report is a significant step to making a straw mill in Montana a reality. However, more information still needs to be gathered to make the project workable. Some of that information can be gathered by consultants, but some must be provided by companies that would bid on the design. A consultant could identify a few possible mill locations then work up a more detailed analysis of local straw availability and of all the various costs incurred prior to the pulping process. The designers of the mill will have to do the analysis of the total equipment, chemical and energy costs for pulping (and bleaching) the pulp, and any systems needed to recover chemicals or treat wastes.

POTENTIAL IMPACTS AND BENEFITS

The direct potential benefits of a straw mill industry are the creation of dozens to hundreds of jobs, an improvement in farmer's incomes, increased activity in the transportation sector, and the creation of a new investment opportunity. These impacts are not expected immediately, as the expectation is that a further review will be conducted and requests for bids to design a fully operational and profitable mill.

Preliminary estimates show that for a 20,000 tpy straw pulp mill using 40,000 tpy of straw would require an initial investment of between $5-30 million. The total economic activity would be $5-15 million/year while loans were being paid off, and $4-9 million/year after the loans were clear. The economic activities that most directly involve the growers are the sale of straw netting $600,000 to $1 million/year and the baling of the straw also brings between $600,000 to $1 million/year. Growers might also benefit through additional income from transporting straw or from investments that they make in the mill.

COMPARING THE STUDY'S FINAL PRODUCT TO ITS INITIAL GOALS

One goal of the study was to develop a specific list of possible financiers and to recommend a means by which investors can cooperate in starting a straw pulp mill. Both of these efforts were only addressed briefly. During the process of bringing the project together, it became clear that to develop such a list before making a specific recommendation or proposal for the mill's production and pulping process was premature. In lieu of specific financiers, a list was developed describing the types of groups, organizations and companies from whom some financing may be available for a straw pulp mill venture. No recommendation was made as to which group or set of groups would produce the best financial arrangement.

Another objective was to improve Montana's recycling program. Since straw pulp is often mixed with pulp from recycled fiber for many products, the development of straw pulping in Montana may stimulate the market for recycled papers, especially the collection of paper types that are not usually collected due to high transportation costs. Although the start-up of a straw pulp mill could still have great impacts on Montana's recycling program, no analysis was done to see how great that effect might be.

In all other respects this report met its goals, and its findings are similar to those expected. With continued research, support, and eventual financing, a small straw paper facility could be in full operation in Montana by 2002, or even sooner. With foresight, when the time comes, straw will be there to help meet the steadily climbing demand for paper, and replace the dwindling supply of available wood.

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INTRODUCTION

> In 1992, treeless paper was made in 45 countries, and accounted for 9 percent of the world's total paper supply.... In tree-rich North America, non-wood fiber has been widely regarded as a poor second choice—a forgotten left-over from 19th-century industries. -Ed Ayres

The question is not whether Montana's straw can be made into paper products, it is whether it can be done economically, using environmentally sound practices throughout the process. Currently, with the Asian economic crisis causing an oversupply of wood and paper products on the world market—and depressed prices—it is not the optimum time to be promoting a new raw material supply or a new mill. Just as the US stock markets have rebound from the "crash" of '98, so too are the world's paper markets expected to rebound, in their typical cyclical pattern. With continued research, support, and eventual financing, a small straw paper facility could be in full operation in 2002, or even sooner. With foresight, when the time comes, straw will be there to help meet the steadily climbing demand for paper, and replace the dwindling supply of available wood.

Montana's grain growers produce about as much straw as grain by weight, as a byproduct of their crop. Agronomic science has shown that the soil needs only part of this straw returned to remain healthy. Currently the market for excess straw is limited to animal bedding and a few specialty products, but there are indications that the market for straw will be expanding in the near future. Montana is in a position to lead the nation in this area.

New developments in paper and fiberboard production have made it easier and safer to use straw fibers to replace wood fibers. Already small plants are manufacturing these products with straw. As this point, these may look like specialty products, but if current worldwide trends continue, the use of agricultural waste fibers will continue to expand. Around the world, over two billion tons of agricultural residues are available, with raw material and environmental costs well below those of wood.

The possible uses of Montana's straw include manufacturing linerboard, newsprint, writing paper, copier paper and various types of fiberboard. In some cases these products are made wholly from straw. For other products, straw will be mixed with wood, recycled, or other nonwood fibers. Currently, PrimeBoard Inc. in Wahpeton, ND, is producing particle board made from straw. Plants such as this one generally use about 50,000 tons of straw annually. Other efforts to use straw for fiberboard are in the works, both in other states and in Montana, partly through the support of the Bear Paw Development Group and the Montana Grain Growers Association (MGGA).

Meanwhile, an hour's drive south of Calgary, Arbokem Inc. has a prototype mill that is producing pulp from straw. This straw pulp is then mixed with pulp from recycled paper to produce acid-free and totally chlorine-free (TCF) copier paper. They use a potassium-based pulping process in a closed-loop system, which captures and returns all the waste water to the system. The pulping liquor effluent is dehydrated into a solid waste that can be used as fertilizer. This process is much lower in pollution than that of kraft (sulfate) mills, such as the one outside of Missoula. Arbokem and similar companies are currently seeking new investors and markets, and a mill of this type may be the best opportunity to use much of Montana's straw.

It is also possible that the best market for straw may be the Smurfit-Stone Container mill in Frenchtown. Although previous studies have shown some difficulties introducing a straw pulp line into a kraft mill designed to pulp wood, it is possible that those problems, largely associated with straw's high silica content, may be overcome. A Weyerhaeuser mill in Springfield, Oregon has tested a process that supports the use of straw in their mill, but have chosen not to release their test results.

OBJECTIVES OF THIS STUDY

The main objective of this study is to benefit Montana's agricultural community by creating a new market for straw. The study investigates the practical aspects and economics of using Montana's excess straw to make paper products, sets a foundation for further research and development, and outlines a plan that facilitates this new market's start-up. As it develops, this new market will create new jobs and new investment opportunities.

To achieve that objective, the study presents the current information on the availability of excess straw in Montana, on transportation, handling and storage costs, and on current straw pulping techniques and facilities. It then assesses various straw pulping techniques in order to make a preliminary recommendation as to the type of facility that would be most appropriate for Montana. The study also looks at the possible markets for straw pulp.

To aid in further research, an extensive bibliography of straw pulping studies and articles is included as an appendix. The appendix also includes four lists of important contacts: technical experts and groups studying straw-paper production potential; facilities currently employing or experimenting with straw pulping; businesses that could design a straw pulping and paper manufacturing mill; and groups of potentially interested investors.

PRELIMINARY CRITERIA

Developing criteria for a straw mill acceptable to the community and the state is an important step in gaining support for the project. The criteria below are not absolute rules or laws. They are simply a guide, developed in part from the literature reviewed, and in part to reflect environmental laws and issue of concern.

- Harvesting of straw for paper production must be kept at levels that minimize short-term impacts to soil and have negligible long-term impacts.

- Small community based mills (10-40,000 tons per year (tpy)) are preferred over larger mills to help develop rural economies and to minimize transportation and energy needs.

- Chemicals used in the production processes should be non-toxic with no toxic byproducts. Chlorine chemicals are not acceptable. Sulfur chemicals should be used minimally or not at all, and in such a way that they will not produce odor. Chemical inputs should be minimized.

- Water and energy use should be kept to a minimum.

- Effluent discharges into natural lakes, rivers, and streams should be minimized or eliminated.

- Processes which produce useful by-products rather than waste are preferred. Ideally, the process employed would produce byproducts that could be used to fertilize cereal straw.

- Straw pulp should be combined with recycled materials whenever possible.

A mill design that follows the criteria above may be more difficult to design, but will more easily gain acceptance and the necessary permits for operation. A guide to making such a mill a reality is provided below.

STRAW AVAILABILITY

> "Nonwood fibers provided the bulk of raw material supplies for papermakers over many centuries, and they still play an important role."
>
> -Leena Paavilainen

HOW MUCH STRAW WOULD BE NEEDED FOR A SMALL MILL?

Al Wong, operator of the only working straw mill in the US or Canada, believes that 45,000 tpy of straw would be needed to supply a 20,000 tpy output mill. This much straw could be gathered from a 20 mile radius on a four-year straw removal cycle (25% removal). This is consistent with soil conservation requirements that generally allow for 25-50% of the straw to be harvested in any given year.

If the Smurfit-Stone operation pulped straw with a similar yield, the 20,000 tpy output would amount to approximately 3% of their total output. Since the linerboard produced at the Smurfit-Stone mill is generally not bleached, a pulping process could be used that may have a yield as high as 60%. At that yield it would take 115,000 tpy of straw for 70,000 tpy of pulp, or 10% of their total output.

MONTANA STATE WHEAT AND BARLEY STRAW STATISTICS

Statistics from the Montana Department of Agriculture website on 5/12/98 showed Montana as the second largest spring wheat producer in the nation, with 6,240,000 acres of wheat planted and 5,930,000 acres harvested in 1997. In addition there were 1,300,000 acres planted in barley and 1,200,000 acres harvested for the same year. The MGGA 1-21-98 bulletin also noted another 1.4 million acres of winter wheat, the lowest in years.

Generally in Montana, wheat and barley produce between 60-100 lb. of straw from each bushel of grain produced (Pan, 1997). It is believed that the amount of residue per acre for spring wheat and barley is directly proportional to the amount of water available to the crop during the growing season (Bauder, 1988). Bauder of Montana State University has found that on average for wheat and barley 3,000 lb./acre of residue are produced. He has also proven that plant height of both spring wheat and barley are directly correlated with the amount of PAW (Plant Available Water). As PAW increases, residue and plant height also increase (Bauder, 25).

On the basis of these figures, over 10 million tons of straw are produced annually in Montana. At 25% removal, a safe figure for soil conservation efforts, 2.5 million tons of straw may be gathered as a raw material for the use in various products, including paper. This is sufficient to 50 small mills in the state or fully supply more than 1.5 mills the size of Frenchtown.

The 2.5 million ton figure is considerably more than the grand total of 658,608 tons of straw from all crops found in the ethanol study from 1984, provided in Table 1. Information on wheat harvested by county from 1990 is provided in Table 5 at the end of this work in Appendix F-1.

TABLE 1: STRAW IN MONTANA 1985 DATA

BASED ON HARVESTING 25% OF THE AVAILABLE STRAW.

County Name	BARLEY STRAW STRAW TONS	WINTER WHEAT STRAW TONS	SPRING WHEAT STRAW TONS	DURHAM WHEAT STRAW TONS
Deer Lodge	330	0	184	0
Flathead	11,009	2,404	730	0
Granite	195	0	97	0
Lake	3,666	2,890	1,282	0
Lincoln	15	0	25	0
Mineral	64	37	25	0
Missoula	358	123	314	0
Powell	750	18	303	0
Ravalli	1,637	205	536	0
Sanders	113	546	88	0
DISTRICT I	18,137	6,222	3,584	0
Blaine	5,061	5,906	8,052	42
Chouteau	9,346	37,181	13,267	238
Glacier	8,509	1,042	5,926	30
Hill	7,518	17,162	22,932	29
Liberty	4,980	5,923	9,403	38
Phillips	3,045	2,834	7,618	0
Pondera	12,570	8,117	3,839	990
Teton	19,304	10,585	4,261	341
Toole	5,388	3,581	7,661	357
DISTRICT II	75,722	92,331	82,960	2,065
Daniels	998	33	10,075	188
Dawson	4,128	5,115	10,177	35
Garfield	1,125	1,073	5,439	0
McCone	3,118	3,438	14,586	62
Richland	3,576	1,559	11,921	34
Roosevelt	1,861	527	15,446	1,727
Sheridan	1,373	142	7,994	7,802
Valley	3,536	1,555	18,573	121

DISTRICT III	19,714	13,441	94,211	9,968
Broadwater	3,740	1,550	3,637	0
Cascade	5,544	8,883	7,157	77
Fergus	13,039	14,111	1,706	0
Golden Valley	496	1,279	163	0
Judith Basin	6,417	5,390	1,771	0
Lewis & Clark	1,841	2,178	397	0
Meagher	323	610	131	0
Musselshell	354	2,100	183	0
Petroleum	346	298	49	0
Wheatland	661	796	296	0
DISTRICT V	32,762	37,196	15,489	77
Beaverhead	2,654	943	2,815	0
Gallatin	12,588	6,008	4,902	0
Jefferson	631	538	256	0
Madison	3,070	746	731	0
Silver Bow	104	0	0	0
DISTRICT VII	19,048	8,235	8,703	0
Big Horn	5,797	15,756	3,410	15
Carbon	2,657	1,597	1,385	0
Park	876	1,501	221	151
Stillwater	1,491	3,569	566	0
Sweet Grass	284	310	112	0
Treasure	777	702	971	0
Yellowstone	10,379	9,663	1,268	0
DISTRICT VIII	22,262	33,097	7,934	166
Carter	861	6,885	1,074	9
Custer	1,799	3,103	1,309	10
Fallon	1,478	3,012	5,636	52
Powder River	1,216	6,035	410	0
Prairie	892	2,390	742	0
Rosebud	3,497	5,160	2,482	0
Wibaux	612	1,292	5,146	181
DISTRICT IX	10,355	27,877	16,800	252
STATE	198,000	218,400	229,680	12,528

GRAND TOTAL OF ALL THE CROPS: 658,608 TONS

Estimating available straw is only one side of the equation. The other element is whether growers are willing to sell their straw. In the North Central Strawboard Analysis, done for the BioGold strawboard project, Russell surveyed 792 growers in the seven county "Golden Triangle" area. From the 269 responses received (about 1/3), he found that these growers produced 456,534 tons of straw during the lowest year of production out of the 4 years from 1993-1996 (See Table 6, page F-2). He concluded that, in the area surveyed, was eight times as much straw needed for a strawboard plant.

Many of the growers surveyed already burned or baled their straw (for their own use or for sale). Forty-three percent of the respondents thought that removing straw benefited their operations, 29% thought removing straw had no effect on their operations, and only 11% thought removing straw was a liability to their operations. The remaining 16% weren't sure how removing straw effected their operations.

Of the respondents, 72% were interested in selling some straw if someone else removed it and another 14% said they might sell some. Of those saying yes, 42% would sell every year and more than half would likely sign a long term contract for selling straw.

AVAILABILITY OF STRAW IN ALBERTA

Some statistic for the availability of straw in Alberta and elsewhere are provided below, in part for comparison, and in part to show that in the long run, there is more straw available than is likely to be used by the growing strawboard market.

Schellenberger finds that Alberta has 13 million acres planted in cereal. After an extensive study that look at total harvest, subtracting from 800-2000 kg/ha for soil needs, and further reducing figures for other agricultural uses of straw, Kraft finds that many Alberta counties have over 200,000 tpy of straw available as a raw material.

AVAILABILITY OF STRAW IN THE US

Atchison (1995) finds that there are 90 million MT (metric tons) of cereal straw available in the US, and potentially 179 million MT of miscellaneous fibers that could be used for paper production. It has been nearly 40 years since there has been significant paper production from straw in the US. In the WWII era of fiber shortages, there were at least 24 medium sized mills in the US run by Mead and Alton, started with the aid of the government. At their height in the 1940's, production approached one million tons. That was most or all of the corrugated medium for the US. Gradually these mills shut down as grain production moved west or converted to wood.

MGGA notes (1-21-98) that 46.6 million acres of winter wheat were produced last year in the US, the lowest in years. Wong, Krzywanski & Chui found that there are 100 million tons of available straw in US of straw, based on one ton/hectare. This level could produce 50 million tons of pulp, or about half of the current wood pulp in the US.

WORLDWIDE AVAILABILITY OF STRAW

Giovannozzi-Sermanniet al. project that there are 2,900 million tons of cereal straw produced annually, and that there will be 350 million tons paper needed in 2010. Based on using 25% of the available straw at a 50% yield, 362 million tons of paper could be produced!

Although figures vary (See Tables 7-11, pages F-3 to F-6), there is complete agreement that production of nonwood paper worldwide has increased faster (6-11% per year) than wood (2-3% per year), although that rate of increase may have slowed recently. Of actual nonwood production, straw accounted for 46%,
bagasse 14%, bamboo 6%, natural plants 18% and the remainder consists of industrial crops (Paavilainen).

Although relatively small at first glance, nonwood fibers play an important role in balancing regional fiber deficits. Atchison (1995) believes that there is 1,175 million MT of straw available annually for use worldwide. He finds that in 1976, nonwood paper production accounted for 7.6 million MT out of 113.5 million MT (6.7%), in 1993 nonwood paper accounted for 20.7 million MT out of 197.1 million MT (10.6%), and projected for 1998 nonwood would account for 23.4 million MT out of 208.5 million MT (11.2%).

Interest in nonwood paper is growing, especially in Europe. Aikman finds that large quantities of wheat, barley, oat and rye straw were used in the British pulp and paper industry in the 1940's and 1950's, but were gradually replaced by wood and more recently by waste paper. In Europe, Onna estimates 100 million tons of straw available yearly, at a market price of 47 Ecu/ton. Paavilainen finds that, "Besides the narrow issue of raw material availability, there are other driving forces behind the growing interest in nonwood pulping. In Europe, the overproduction of food and the large subsidies delivered to the agriculture sector have resulted in a need to find alternative uses for grain fields."

THE ECOLOGICAL IMPACTS TO SOILS OF UTILIZING WHEAT AND BARLEY STRAW FOR PAPER PRODUCTION

Any endeavor that uses a significant amount of straw from a given area justifiably raises a number of question about the effects that removing straw will have on the soils, other elements of farming practices and the environment generally. The basic question is, "How much residue should remain on the field to prevent soil erosion or nutrient loss?" Farmers need a good grasp of the answer to this question and they must closely monitor their soils and yield in order to prevent the sale of straw from becoming a detriment to their operations.

This section addresses some of the following issues,: What does removing soil do to erosion rates, and the levels of nitrogen (N), phosphorous (P), and other nutrients in the soil? How will straw removal affect pesticide application, seed sprouting, soil temperatures, moisture retention, and yields? How do various tillage practices affect the level of straw available for removal? How do the effects of straw removal compare with residue burning? Finally, this section addresses additional questions, provides recommendations to the farmer, and recommends further studies that could provide better answers to some of these questions.

Before addressing the questions, it is useful to present some definitions used for different tillage practices. A clear understanding of different tillage practices will be integral to the discussion that follows, as many of the studies that have looked at straw removal revolve around comparing different tillage practices.

DEFINITIONS OF VARIOUS TILLAGE SYSTEMS USED IN US AND CANADA[1]

Conservation tillage (CT)- Any tillage and planting system that attempts to cover at least 30% of the soil surface with residue, after planting, to reduce soil erosion by water. The following four types of systems are forms of conservation tillage:

1. Reduced tillage- Tillage types that leave 15-30% of the residue cover after planting, or 500-1000 lb/acre of small grain residue.

2. No-tillage (NT)- No tillage operations are performed between harvest of one crop and planting of the next. Generally all available residue is left.

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[1] Definitions from University of Guelph OMAF Website.

3. Mulch Tillage (MT)- Mulch tillage systems disturb the soil at some point between harvesting one crop and planting the next, leaving some residues on the surface. More than 30% of the soil surface is covered with residue after planting.

4. Ridge Tillage- Crops are planted on raised ridges and no tillage takes place between one crop and the planting of the next. Ridge tillage works best with row crops, although some producers grow cereal crops on ridges.

Retaining 15-30% of residue: This system does not meet the residue requirements to qualify as conservation tillage. This system does provide some level of erosion control and water quality benefits.

WHAT DO RESIDUES ADD TO THE SOIL?

Incorporation of crop residues in or on the soil generally increases the organic matter content of soil, and increases in the total nitrogen in the soil (Prasad, Greb). Crop residue on the surface leads to their oxidation at a rate that is slower than tilling them under, but still allows the residue to be transformed into 'beneficial' humus (Bauder, 25). It has also been found that potassium accumulates near the soil surface in NT systems resulting in increased soil test P levels (Follet, 1988). Most relevant studies have shown an increased accumulation of plant nutrients in surface soil layers under no-tillage systems. One study finds that the stratification of nutrients under NT was not a detriment to plant growth and that root activity and water and nutrient uptake from deep in the soil profile were greater for NT than CT (Hargrove, 1985).

Leaving crop residue on the soil surface leads to reduced pH in the top 5-cm of soil and often at deeper depths (Prasad, 1991). One study finds that the presence of 150% of the crop residue increased the soil organic matter by 10%, increased the total nitrogen content by 12% and NO_3 content by 66%. The study concluded that increasing the no-till crop residue rates increases the capability of this soil to provide nitrogen to growing crops for many years (Maskina, 1993).

EROSION, SOIL LOSS AND THE FEASIBILITY OF STRAW REMOVAL

Crop residue management is an important component of soil erosion control. Soil erosion results in topsoil loss, decrease in soil productivity and contributes to the siltation and nutrient pollution of our waterways (Pan, 1997). As a result of these problems, proper site selection for straw harvesting is crucial. Productive soils with low susceptibility to erosion are the most likely sources for straw for pulping.

Soil loss through erosion is generally caused by five main factors: vegetative cover, tillage practices, management of residue from previous crops, rainfall and soil characteristics.

Additionally, in Montana, most soil loss is from wind (Bauder, 1997). It has been found that eroded soils have lower water-holding capacity, slower water infiltration rates, poorer structure and different pH values. In Ontario, crop yield reductions of up to 50% have been documented on severely eroded soils (OMAF). Tillage has the ability to increase the rate of erosion.

Residues burned, removed, buried or decomposed before an erosion period may provide insufficient cover to protect soil (Douglas, 1980). Conservation tillage keeps a sufficient crop residue on or near the soil surface to prevent or decrease erosion. Stott finds that over the course of a year, plots retaining 1680, 3360, and 6720 kg/ha lost 75%, 72%, and 50%, respectively, of that residue, under a no-till operation. More residue was lost with chisel and moldboard tillage. Microbes were considered the largest factor in the loss. Other factors included wind, fragmentation, insects and other soil fauna.

Residue decomposition rates must be known in order for farmers to be able to safely remove excess residue, while still leaving sufficient residues on soil surfaces for erosion control (Douglas, 1980). Greb finds that conditions in the Great Plains are not favorable for decomposition. This could potentially lead to problems associated with excess residue. There are four equations that can be used to estimate decomposition of cereal residues based on cumulative degree days (Douglas, 1980). Douglas also finds that residue decomposed much fastest in the soil than on the soil, and that decomposition is inversely related to load.

If soil erosion by wind is a concern, tillage systems should maintains at least 1,000 lb/acre of small grain residue on the surface throughout the critical wind erosion period (Purdue University, Crop Management Residue 1995). Stott finds that standing stubble tended to anchor other residues. Other researchers believe that 1,500 to 2,000 lb./acre of residue should be left for sufficient wind erosion control on either wheat or barley operations (Bauder, 25).

Generally 3,000 lb/acre of residue are produced with most cereal crops. Leaving less than 30% of the soil covered with crop residue greatly increases the risk of wind, water and tillage erosion for erosion-prone soils. Leaving only 20% residue cover on the soil will reduce erosion by 50% compared to leaving no residue on the surface. Increasing residue cover to 30% after planting will reduce erosion by 65%. Combining these practices with reduced tillage will result in higher erosion reduction rates (OMAF Website). Washington State University research showed that maintaining 1000 lb/acre residue reduced erosion by 90% (Pan et al.). Crop rotation that includes perennial legumes, grasses and winter cover crops may also improve soil structure and reduce soil loss.

THE EFFECTS RESIDUE LEVELS ON SEED SPROUTING, SOIL TEMPERATURE AND MOISTURE RETENTION

In some areas there are problems with NT management that retains 90%+ of crop residue. High residue can slow soil warm-up in the spring (OMAF). In cooler, wetter soil, there tends to be a shift from annual to perennial weeds. This creates a need for increased management inputs. There is often a delay in seeding because of wet soils. Grossbard (1979) finds that there is more residue to deal with, and an increase in weeds, disease and insects.

On the positive side, it has been found that residue-covered soils tend to have greater water content than bare soils, except after extreme drought (Prasad, 1991). NT systems lower raindrop impact energy, reduce soil particle detachment and runoff, and decrease transport of sediments and agricultural chemicals (Dao, 1991). Reducing the evaporation rate of soil water is one of the major advantages of leaving crop residues on the soil surface and has made NT and MT very popular in midwestern US, Canada and other subhumid, semiarid parts of the world (Unger, 1986). Fowler finds residue can act as a water collector/retainer in the spring runoff and that stubble from a spring/summer crop can reduce risk of winter overkill for winter wheat.

The amount of residue cover is also important in determining water storage in soil under NT. A study finds that standing stubble will trap as much as an additional 2-3" of moisture over the course of a winter (Bauder, 1997). Residue management can significantly influence soil temperature due to change in radiant energy balance and insulation (Unger, 1980). It is generally assumed that residue cover on soil lowers soil temperatures and delays emergence of spring-seeded crops, but additional water conservation in mulch-covered soil often offsets any adverse early season advantages (Prasad, 1991).

NT management provides a favorable environment for soil- and surface-residue-dwelling organisms because of reduced water loss, amelioration of temperature extremes and fluctuations, and the presence of a relatively continuous substrate for decomposers (House, 1985). Microorganisms like bacteria, actinomycetes, fungi, earthworm and nematode populations were greater under stubble mulch than under various conservation tillage systems (Ocio, 1991).

THE EFFECT OF STRAW REMOVAL ON PESTICIDE APPLICATION

Dao finds that the presence of excess residue in the soil can create some problems in retaining certain pesticides and herbicides, and by retaining others. Some pesticides and herbicides stay on the residue and create problems for the new crop. If this is carefully measured, it can allow for lessening application needs and prevent the runoff of excess. In other types of soils, NT and residue retention can increase the rate that moisture, along with pesticides and herbicides, migrates down into the water table (Greention), where they can impact water quality.

THE EFFECT OF STRAW REMOVAL ON GRAIN YIELD

One study finds that wheat planted directly into soil mulched with straw of a previous wheat crop typically grows and yields poorly relative to a seed bed prepared with straw residue burned or buried (Cook, 1991). Stott finds that too much residue can create yield reductions. Prasad finds, "In wetter and cooler regions of the world, or on poor drained soils, crop yields may be lower when crop residues are left in situ, and NT planting is utilized." Wheat yields were enhanced by conservation-tillage in areas with low annual rainfall and high evaporative demand. The alternative is to burn the stubble and associated straw residue, which can give the soil relief from the yield depression associated with planting wheat into soil otherwise left covered with residue (Cook, 1991).

ADVANTAGES AND DISADVANTAGES OF VARIOUS TILLAGE AND RESIDUE MANAGEMENT SYSTEMS

Various tillage systems result in a variety of impacts on the land. The discussion above briefly outlines the effects that residues have under different tillage systems. Cereal stubble and straw are widely used in the US and Canada to reduce wind and water erosion and to conserve soil water. Crop residues are frequently managed by stubble mulching wherein stubble is undercut to control weeds (Prasad, 1991).

"Leaving residue cover on the soil surface as practiced in conservation tillage or NT may have positive, negative, or no effect on grain yield, depending on soil-climate conditions" (Prasad, 1991). One negative factor can be an excess of residue on the soil surface, leading to the following problems: nitrogen immobilization, problems with seed placement, variable plant population, increased number of pests, incidence of plant pathogens, production of phytoxins, and potential for a soil environment too cool and or wet for optimum biological activity (Prasad, 1991). Tillage of all kinds leads to a decrease in soil organic carbon and nitrogen as compared to native sod (Prasad, 1991).

The beneficial effects of leaving surface residues include water conservation, soil erosion control, reduced winter kill, and maintenance or enhancement of soil organic matter with its attendant improvement in the soil environment (Prasad, 1991). In addition, leaving surface residues greatly reduces labor inputs per acre, as well and lower equipment costs. Farmers can help to counteract the problems associated with residue inhibiting young seedling growth by increasing the seeding rate 10-20%. This results in similar seedling yield as conventional systems (Bauder, 25).

Tillage has been found to be the single most important factor influencing the number of earthworms present in soils. A greater number of earthworms were found in no-tillage versus chisel-disk plots (Jordan, 1997). Earthworms play a major role in overall soil fertility and productivity, particularly in clay soils. They can increase the water infiltration by 2 to 10 times in some soils (Jordan, 1997).

Conventional tillage, the traditional method of residue management, attempts to cover most of the residue, and leaves less than 30% of the soil surface covered with residue after planting. The advantages of this system are widely available machinery, its flexibility and adaptability to a wide range of soil and crop condition and manure handling systems. Tillage may be used to control weeds throughout the growing season, and soils warm faster when crop residues are incorporated (OMAF). However, there are some significant disadvantages of this system. These include high equipment, fuel and labor costs, soil compaction, increased risk of soil erosion by wind and water as well as crusting, and reduction in organic matter level (OMAF).

SOIL TYPES AND APPROPRIATE TILLAGE SYSTEM

Soils which are well drained because of soil texture, depth to water table and slope perform well under conservation tillage systems since they can dry and warm quickly under crop residue. Poorly drained soils, like ones found in depressions, or low-lying level land conditions, seldom erode and work well under various conditions.

BENEFITS AND DRAWBACKS OF BURNING

Burning is an inexpensive, labor-efficient means of removing unwanted crop residues prior to tillage and seedbed preparation (Bauder, 1983). In addition to removing excess residue, burning is also a way to control weeds, insects and diseases. The benefits of burning crop residue are overshadowed by the fact that long-term burning of straw has an overall negative effect on the soil compared to normal conditions, or adding straw, by decreasing organic matter, total nitrogen, extractable carbon, polysaccharides, ammonium and phosphorus (Bauder, 1983). In addition, the burning of wheat straw deteriorates air quality and the carcinogenic compounds found in smoke from field burning raises important health issues. It is estimated that 45,000 tons of particulate, carbon monoxide and other volatile carbon compounds are emitted with wheat straw burning each year in Washington (Pan, 1997).

It has also been found that the heat from burning residue only penetrated the soil to a depth of 1/2 inch, allowing the insects and diseases to continue living below that level (Biederbeck, 1980). The same study found that bacteria, nitrogen and carbon were all decreased as a result of burning. Burning appeared to increase the erodibility of the soil, reduced the water intake rate and increase the soil density (Biederbeck, 1980). Burning of crop residues often produces a variable effect on soil organic matter content, which depends on soil depth, tillage practices, degree of burning, time and other factors (Prasad, 1991).

Many researchers believe that short-term burning of straw has no permanent negative effect on soil properties or crop yields and that infrequent burning may improve immediate crop yields (Bauder, 1983). It should be emphasized, that with long-term burning has been proven to have detrimental effects. Many farmers commonly believe that repeated burning and the associated negative effects can be overcome by proper fertilizing practices. Research has proven this generally untrue (Bauder, 1983). Burning may appear to be saving fertilizer, pesticide and tillage costs, but it will eventually result in increased costs due to loss of organic nitrogen and carbon. A twelve-years study of managing straw by burning vs. incorporation conducted in Texas found that straw incorporated plots had a higher organic matter content and showed less compaction of soil that the plots where residue had been baled or burned (Biederbeck, 1980).

Many studies have find that the effects of burning are similar to baling and removal of all the residues. William Pan of Washington State University finds that when straw is removed and followed by no-till cropping, organic matter levels of the surface soils can be improved over conventionally tilled systems (1997). It should be understood that burning and removal do not have short-term effects, but rather long-term effects that may take a significant period of time to become evident (Prasad).

QUESTIONS THAT STILL NEED TO BE ANSWERED

Although there have been numerous studies of various cropping systems and their effects on soils, many of which examine residue burning, there have been few general or systematic studies of residue removal and its long term effects. The author could not find any published studies that were specific to straw removal in Montana. More information and a systematic study is needed to determine which soil types are appropriate for various tillage and residue systems, and what levels of residue removal can be maintained with little or no adverse effects. Along with studying nutrient levels, other key elements need to be considered to determine the amount of residues that can be removed, such as soil temperatures, total yield and water availability in soil. The startup of the BioGold strawboard plant would provide an excellent opportunity for such a study.

WHAT PERCENTAGE OF RESIDUES CAN SAFELY BE UTILIZED?

The answer to this question is dependent on a number of factor, and there are a variety of opinions concerning the amount of residue that should be left on soil and the tillage system used. There seems to be a huge faction of researchers who feel that a conservation tillage system, in which significant percentage of residue is left on the surface of the soil, is crucial to soil health. Various sources suggest that soil type, precipitation rate, wind, and tillage system all factor into this question.

Most researchers are advocating leaving at least 30% of the residue on or tilled into the soil in order to achieve the goals of erosion control and maintaining nutrient levels. NT often leaves 90-100% of the residue, and as various evidence demonstrates, this can often lead to serious problems but also provide some long-term benefits. In areas of excess straw production, removal of some straw, while leaving enough for soil protection, could help facilitate no-till or reduced till planting.

Some advocates of using straw as a source of fiber for paper or other products believe that large quantities of straw that result from a harvest which are typically plowed in or burned can be removed. They argue that excessive straw impedes planting operations, and economical straw removal from these areas would benefit the farmer without increasing the soil erosion potential (Pan, 1997). Even these advocates rarely argue that more than 50% of the residue should be removed consistently from any given area.

Many researchers now base their estimates of the straw available for removal at 25%, or full removal once every four years. In most areas this seems to be a reasonable basis to start straw removal levels that is unlikely to have serious negative effects. If further studies show that this level of removal is not harmful, it can be increased gradually. If adverse effects occur, removal can be stopped or curtailed. In areas that are consistently burned, experiments could start with alternate years of removing and burning straw, or a three year cycle of burning, removal, and spreading residues to add nutrients.

THINGS FARMERS NEED TO KEEP TRACK OF IF THEY DECIDE TO SELL RESIDUE

1. Snow trapping ability of the standing stubble must be adequate to ensure successful over-wintering of winter wheat and tritical. If more soil moisture is need, farmers should try no-till or reduced tillage. This management system can be very useful in Montana and its dry soils.

2. Water is normally the most limiting factor for crop production: snow trapped in standing stubble, retained in profile as melt water the following spring, is potential for money in the farmer's pocket.

3. Crop residues must be managed so they do not interfere with seeding operation. Spreading residues out uniformly is critical, so they do not interfere with winter cereal stand and uniformity of development. In addition, farmers can increase seeding rate by 10-20% to compensate for residue cover.

4. Farmers also should make sure they have some form of erosion control measure implemented such as conservation tillage, crop rotation, strip crop-tilling and cropping across the smooth slopes, and installation of erosion devices.

5. Farmers should frequently measure the soil quality by measuring the organic matter content. See Montana State University Agronomy notes #46 for details on how to do this. Erring on the safe side most likely means removing less of the residue rather than more.

STRAW TRANSPORT, HANDLING AND STORAGE

It is generally agreed that the expenses incurred to collect, bale, handle, transport, and store straw, all incurred before the straw is actually put into pulping process, will be critical to whether the operation is financially successful. Obviously, the cost incurred to clean, pulp, and bleach the straw are important as well, but they are often less than the cost of getting straw to the mill.

To get a true sense of the costs of bringing the straw to the mill, it is imperative to consider the expected yield of the operation. Yields vary with different processes, but for every ton of straw that enters the mill, 0.3 to 0.8 tons of pulp are produced. If the average yield is 50%, that still means that two tons of straw must be baled, hauled, and handled, and these costs are incurred for both tons. In addition, other losses during handling, transport and storage have to be factored in. Yield from wood-based pulping is actually comparable. One of the biggest cost difference between wood and straw is in transporting it, as wood is much denser than straw.

Due to these transport costs, most authors agree that a successful operation will generally need to be supplied by farms in a maximum of fifty miles radius from the mill, and some suggest that a thirty mile radius is a better formula for success. Wood chips, by comparison, are often hauled from a radius of between 100-200 miles, and sometimes further. This author is not in complete agreement with setting the limits of straw transport at 50 miles and instead sees the obstacles of transporting bulky straw from longer distances as an engineering challenge (discussed in more detail below), or as variable with the costs of other fiber sources.

Since this report is not tied to a specific mill type, size or location in Montana, the information below is meant to guide the process for selecting a site for any straw mill that is proposed and for making general estimates for the cost of bringing straw to the mill.

BALING

There are four basic questions that need to be addressed in planning to bale straw as a commodity: Who will bale it? When? What kind of bales will be used? and, What is a reasonable price for baling? Implicit in these three questions are also the issues of what kind of equipment will be used and who does or should own it.

The collection and baling of straw can be done by the growers themselves, by local contractors (usually other growers), or by mill employees. The best solution is probably some combination of the above, as it allows the most freedom of choice for the growers. The growers can bale as much of it themselves as they are willing to, then willing neighbors can be contracted to bale more. To supply a larger mill, it is likely that additional contractors may be needed in addition to the growers themselves. It may be less expensive in the long run for the mill operation to buy baling equipment and have employees bale the hay. If baling is done by contractors, some growers expressed concerns that their balers would spread noxious weeds and recommended that the baling equipment be cleaned regularly.

The North Central Strawboard Analysis done for the BioGold strawboard project[2] showed that more than 25% of growers already baled some of their straw either for their own use or for sale. The same study showed 72% would be interested in selling their straw if someone else baled it and removed it, while only 14% would rather bale their own straw. The twelve respondents who responded with certainty about custom baling believed they could bale 11,700 tons over a six-week period.

The study also finds that most of the growers want the baling to be done and the bales removed from the fields 2-4 weeks after harvest. Another study suggested that the best time to do the baling would be along with the harvest so that the straw did not spend time on the ground collecting dirt. This might be beneficial for some processes, but is probably impractical, and the straw would almost certainly have to be cleaned anyway. The Weyerhaeuser project report finds that harvest procedures were not critical.

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[2] Another project sponsored in part by the Montana Department of Agriculture's Growth Through Agriculture Program.

Although some pulping processes prefer a low moisture content in their bales, the report done for the Weyerhaeuser project finds that bales with higher moisture content (~20%) were denser and held to gather better after storage and multiple handlings. This could be achieved by baling in the morning while there is still dew on the straw. Jeyasingam recommends bales to be stored at between 10-12% moisture, and definitely less than 15%. Otherwise there is a risk of higher chemical consumption and poor yield, strength, and brightness. This important difference in baling practices would have to be resolved through experiments after a pulping process is chosen.

Most research on the issue suggests that for long-term storage, handling and the most economical transport, the large rectangular bales (generally 4'x4'x8' Hesston or 3'x4'x8' Freeman) are the best type for straw as a commodity. Most of the growers who responded to a survey in the "Golden Triangle" area of Montana had large round balers.

In the North Central Strawboard Analysis, most of the growers surveyed thought $45/ton was a fair price to sell straw that they baled, compared to their wanting half that for loose straw. It is likely that contractors or employees could bale straw for less than $22.50/ton. Curiously, the growers surveyed who were interested in becoming custom balers thought on average that $17/bale was a fair price to ask for baling. The Weyerhaeuser project report estimates baling costs are between $17-24/ton. Another study completed in 1994 by the Cochrane Group put baling costs as low as $11.65 for straw in Western Canada. (See Table 13, page F-8.)

HANDLING

The basic formula for handling straw is to do it as little as possible to minimize both costs and damage to the bales. It is important to factor in losses due to handling when estimating total yield. The Cochrane Group projected a cost of $2.65/ton for loading. Weyerhaeuser project estimates an additional $1.96/ton every time the straw is loaded or unloaded.

TRANSPORTATION

The issues that need to be considered to make a good estimate of transportation costs are the shape and density of bale used, the vehicle capacity, the distance traveled and who would do the hauling. The results from the North Central Strawboard Analysis showed 19% of growers are clearly interested in self hauling straw to mill, with another 33% unsure.

Various studies put straw bale density typically at between 7-12 lb/cu. ft. Based on practical experience, the Weyerhaeuser report finds that between 15-20 tons could be transported on a tractor with two 32' trailers (or a 40' and 24' trailer combination). This was based on a load of 48 Freeman bales (40,800 lb.) or 32 Hesston bales (29,600 lb.). This translates to between 9-13 tons per load for a 40' trailer.

The North Central Strawboard Analysis finds that growers willing to haul their own straw would ask $9.13/ton for 1-15 miles, $13.44/ton for 15-30 miles, $18.56/ton for 30-50 miles. Although it isn't clear from the study these costs are likely to include loading bales from the field, though probably not unloading of the straw at the mill or collection site. The Cochrane Group projected hauling costs at $9.20/ton, based on 30 miles of travel. The Weyerhaeuser report finds the cost to be $3.20/ton for 0-10 miles and $4.96/ton for 11-25 miles. This was based on some entity (probably a cooperative) buying and operating their own fleet of used trucks with trailers. For a mill based near the straw, having such a fleet, or signing extended contracts with independent haulers, clearly makes more sense that hiring haulers through normal channels.

With the owner operator system, one could extrapolate the Weyerhaeuser report's numbers (adding $2/ton for each additional 15 miles) to find a cost of approximately $9/ton for 55 miles or $29/ton for 205 miles (the distance between Great Falls and Frenchtown). With this system, it would take about $40/ton to haul straw from an "average" place in the "Golden Triangle" to the Frenchtown Mill, although most of the straw needed for an operation there could probably be supplied from within a 200 mile radius. Using independent haulers or freight, the cost would be from $40-70/ton, based on estimates of between $500-700/load from BNSF railroad and local trucking contractors.

The calculations above are all based on bales averaging 8-10 lb/cu. ft. It may be possible to cut these costs by half or more. In their examination of a pulping process, Giovannozzi-Sermanni and others experimented with using straw hypercompaction-pressed to 500-1000 kPa to reduce air and induce permanent (positive for pulping) modifications to the plant structure. This compaction increased density from between 100-300 kg/m^3 to over 1000 kg/m^3 or approximately 60 lb/cu. ft.

If such a system is used before hauling, the high level of compaction may even be greater than necessary, as straw packed at 60 lb/cu. ft. would fill a 10x10x40' trailer with 120 tons! Compaction at less than half that level would allow tractor-trailers and rail freight cars to haul straw at their normal weight limits which would bring freight costs down to a level similar to logs and wood chips. This could bring the hauling costs from the "Golden Triangle" to Frenchtown down to as little as $10-15/ton.

Developing a compressed transport system would take some research and engineering. What would be needed is a mobile compressor that traveled to the source of the straw and formed it into compressed bales. These bales would almost certainly need special containers or special strapping. The containers or strapping would have to be reusable to make this idea feasible. The idea would be to make only enough storage units to feed the mill for one-two weeks, then bring them back to the fields for reuse. Special units may also be needed to decompress the bales. The compressors, decompressors and storage units would require a considerable investment, but since transportation costs for a straw mill could easily cost more than $1 million/year, that investment could pay for itself over a short period.

Finally, to make sure that compressed transport was workable, the effects on the straw would have to be examined closely. It may not be suitable for some pulping processes. The straw may be storable in such units for only a short time without affecting the fibers negatively, or they may be unaffected by long storage. It is also possible that such compression could have a positive effect on the pulping process.

STORAGE

Along with cost, there are two main issues regarding storage. The first is location, and the second is whether to cover the straw, and the type of cover to use if it is covered. The three basic options for storage are on the farm, a central location near the farms or near a transportation center, or near the mill. Covering options include uncovered closely packed bales, tarps, or large storage barns made from various materials with various designs.

In many cases the farms will have to provide at least temporary storage of the baled straw. To reduce the number of transportation links and the number of times it is handled, it may make most sense to keep at much straw in the fields as possible. The North Central Strawboard Analysis finds that 40% of growers would be willing to store straw on their land and another 31% might consider this option. If straw is stored on or near the fields, any losses due to weathering or handling could easily be reused by the grower through composting or for residue to cover the soil.

Another good option is to bring the straw to the mill directly from the fields. For long distance hauling, storage near a rail access site or main highway makes sense. The Weyerhaeuser project incorporated four different storage sites: in-field storage at a cost of $0.50-1.50/ton; on-farm pole barns with rock floors at a cost of $7.18-957/ton; tarped super-bales stored near their special preprocessing centers (where it was cleaned and depithed) at a cost of $3.08-3.48/ton; and on-site steel barns with rock floors at preprocessing centers at a cost of $8.73-15.04/ton.

The PrimeBoard mill stores and processes large amounts of straw. They store the hay in large rectangular bales of nearly a ton each. The bales rest on bare clay soil and are packed closely in huge piles 50 bales long by 6 bales wide by 6 bales high. The large piles are left uncovered. Evidence from where bales were removed showed that only the outer six to twelve inches are affected by the elements. This is probably the most sensible storage option for this region, although the pulping process chosen might affect the choice of cover. The NACO mill in Italy finds that straw that has been left uncovered for as long as 5 years can still be used. The Weyerhaeuser project used large specially constructed barns costing millions of dollars to store the straw for their mill. This seems excessive, but might be required in Oregon with its heavy rainfall and high humidity levels.

Some experts recommend tarps to store straw. Straw might be stored in cotton-like modules about the size of a rail car. The module covers cost approximately $25-30 per cover and can last up to 3-5 years. This would cost about $0.50-1.00/ton. In dealing with $100/ton hay used for feed and often shipped overseas, Ritchie finds that large 25 x 54' Super Tarps, with rope and stakes costing $310 to $384, pay for themselves by saving 12-20% from water damage and maintaining the hay at a better overall quality. The tarp can cover 66 bales to 72 bales, or about 33 tons of hay, for a cost of $10-12/ton. Over the four-year life of a tarp, the cost is just $2-3/ton of hay covered. It is difficult to determine if such tarps would make sense in Montana, but they would probably be more economical than building special barns.

PREPROCESSING

The requirements of preprocessing of straw before pulping vary with the pulping process selected. Most pulping processes require that the straw be chopped and then cleaned of dirt, leaves and at least a portion of the ash content. Many also require that the nodes along the stem be removed, although some pulping processes screen the nodes after pulping.

There are two basic cleaning procedures: wet cleaning and dry (air) cleaning. Some companies that have explored the use of straw believe that the preprocessing steps should take place outside of the mill to reduce waste streams internal to the mill. Dust control is an important issue for preprocessing systems. Some preprocessing systems collect some of the wastes from the processing to make marketable byproducts including wax and animal feed. (See Figure 2, page F-9 for a generalized diagram of the preprocessing steps.)

PREPROCESSING AS IMPLEMENTED BY WEYERHAEUSER

Perhaps the most extensive description of a preprocessing system found in the literature comes from the Weyerhaeuser report. Using an air cleaning system, they tried initially to clean and prepared the straw in a mobile unit but quickly found that the process created too much dust. They proceeded to build an indoor pilot preprocessing plant with a 50 tpy capacity and found it necessary to install extensive dust control equipment.[3]

Much of their system was based on the system, considered the most advanced in the world, developed by the Danish "The Whole Crop Biorefinery Project." Weyerhaeuser sent them ten tons of straw for processing during their initial studies of the Oregon project, and apparently were happy with the results.

A Road Runner bale squeezer was used to handle and stack bales, and after some experimenting Weyerhaeuser found that a pneumatic conveying equipment worked best for dust control. In their initial step they used a WHO tub grinder to break up bales, followed by a United Milling milling machine.

Following milling, they used air density separation equipment (ADS) that both removed dirt and separated the chips from nodes. A multi-deck oscillating screen proved very efficient for the final cleaning of dirt, fines and pulverized nodes. A BM&M screener was used and found acceptable. They then transported the straw from the preprocessing site to the mill in "slip" painted containers after condensing it with a screw press to 12 lb/cu. ft. Several fires were reported in storage and transport containers.

In their system, Weyerhaeuser experimented with the leaf, nodes, and other organic material wastes from processing and pelletized them for animal feed. The material pelletized easily and was found to be both nutritious and palatable. Cows even preferred the pellets over alfalfa! They estimated that the pellets could be sold for between $60-100/ton or higher if the fiber content was reduced. They expected that virtually all of the preprocessing waste could go to this use, which amounted to 16-24% of the total straw. Initially it was thought that this material could be used in particleboard manufacturing, but it proved uncompetitive with wood as prices went down.

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[3] Jeyasingam describes a very similar cleaning system, although he recommends the German manufactured star cutters for chopping, as they can take large bales and reduce them to 1-1 1/2 inch lengths at 8-14 tons/hour. He also notes that tub grinders are preferred for cylindrical bales.

They initially thought that wax could be a problem if the straw was too fresh, and it was recommended (source unknown) that the straw for three months before use, but the length of storage did affect processing at the mill. Other potential problems associated with aging, moisture content, variation in species and variations in harvesting and baling systems did not prove significant either, although ryegrass was found to run somewhat better than wheat straw.

WET VS. DRY CLEANING

Jeyasingam finds that wet cleaning is more effective but uses more steam and creates variations in consistency due to the required screw press extraction. He also finds that overall it has a lower yield and lower efficiency. Atchison sees wet bulk storage and cleaning as an option in some cases, usually where the highest quality bleached pulp is desired. Generally, most sources find dry cleaning systems fit their needs and are the most economical for wheat straw, although possibly not for rice straw.

FIBER PROPERTIES AND POTENTIAL END USES

GENERAL CHARACTERISTICS

The straw in Montana comes from a variety of cereals, mostly wheat (Triticum aestivum, Triticum durum and Triticum spp.) and less often from barley (Hordeum spp.), rye (Secale spp.), sorghum (Sorghum spp.), millet (Panicum spp., Pennisetum spp. etc..) and oats (Avena spp.). Rice straw (Oryza sativa) is often used for papermaking but is not grown in the state. Straw pulps are often considered inferior to wood, however with proper pulping, they have characteristics that can enhance the end products

With the exception of rice straw, the variation in straw fiber due to species appears to be minor. Other characteristics may create some variation in fiber quality. Pan finds that irrigated straw tended to have slightly higher fiber length, but that overall variations were not extreme. Eroglu and Deniz find the ash content higher straw grown in heavy soils.

Overall on average straw fibers are similar to hardwoods, with an average fiber length of 1.0 to 1.5 mm, but straw tends to have a wider overall distribution of longer and short fibers. (See Table 12, page F-7, and Figure 1 page F-8.) Short fiber tend towards lower tear strengths, thus straw is not generally good for tissue products. Schellenberger finds the length to diameter ratio (115:1) make superb paper for some other uses.

Straw has a relatively small open cell structure and silica-rich epidermis This is an advantage in that it allows for almost instantaneous liquor penetration, but creates a drawback in that the fiber has poor drainage characteristics. Due to high hemicellulose and fines content, straw has a good bonding ability. Many researchers find that straw pulp tends to bond better that wood. Papatheophanus notes that pulps with decreased hemicellulose have better mechanical properties.

Compared to wood straw is low in lignin, thus less time, energy and chemicals are required for cooking and bleaching. Somewhat higher in cellulose than wood, it is generally somewhat higher in yield. Overall straw has a low bulk density. With an average of 5-6 nodes on each stem, straw requires some de-pithing. This adds to overall costs. Similarly, the high silica content can cause problems, as most existing technology is designed for longer fibers and a less silica-rich liquor.

STRAW FOR USE IN LINERBOARD AND CORRUGATED MEDIUM

Outside of India and China, straw is most commonly used for linerboard and corrugated medium. It is generally considered simpler and easier to produce pulp from straw for these uses. Aikman finds that when blended with hardwood pulps, semi-mechanical wheat straw increases the strength and fluting properties. Atchison also find that straw can increase stiffness and may improve edge crush.

Wong, Krzywanski and Chui find that when a mixture of 20% semi-mechanical wheat straw pulp was added to linerboard it had comparable strength to linerboard without the straw. They also find that a blend of 10-20% wheat straw pulp would require 10-15% less energy for production. They recommend a system in which wheat straw is readily defibrated under moderately elevated pressure and temperature conditions. The mechanically-defibrated pulp will retain its yellowish straw brightness. Since no pulping chemical is used, all surplus process liquid can be readily recycled to farm soil.

STRAW FOR USE IN FINE (BLEACHED) PAPERS

Straw pulp is high in fines that add smoothness to paper, a quality desired in printing and writing papers. Good quality newsprint grades are already manufactured from 50/50 blends of hardwood and straw, with good strength and optical properties (Aikman). The optical properties are improved by the high fine content that create good light scattering characteristics. This is desired in newsprint, so that one doesn't see light through the paper.

Aikman also finds that "The high fines content together with a high hemicellulose content in pulp might limit runnability on high speed machines if straw is used without pretreatment, the portion of wood pulp is below 30% or double-felted pre-drying is used. The fines might also cause quality (linting) problems in printing. Consequently, proper raw material pretreatment should be taken into account in process design."

Simonetis, using an acid prehydrolysis with chlorination pulping and bleaching process, finds that straw pulp responded to beating differently than wood pulp. Generally beating increases freeness and bonding, and softens the fibers through fibrillation, although some unwanted cutting of the fibers occurs. With increased beating of straw, tearing strength increased first, followed by tensile and bursting strength. Folding and tearing strengths are influenced by fiber length as well. He finds that beating properties and equipment can be controlled to some degree to influence desired properties.

STRAW FOR USE IN DISSOLVED PULP

Experiments have looked at separating straw into its various components to make multiple products. A few have experimented using chloroform, hydrochloric acid and methanol to extract the wax coating. The lignin removed is one of the most abundant naturally occurring polymers and can be used in a variety of products. The cellulose and hemicellulose can be extracted for use in dissolved pulp for specialized products.

SELECTING A PULPING PROCESS

Numerous processes are available to pulp straw. They vary as to the equipment needed, the chemicals, temperatures and pressures used, energy and water requirements, and the amount and nature of effluent produced. They also vary as to how they deal with preprocessing the straw, and the problems of high silica, relatively high potassium, cooking liquor recovery and effluent treatment. As processes vary, so does the quality and bleachability of the resulting pulp, and its suitability for different products. (See Figures 4-7, pages F-10-12 for diagrams of different pulping processes.)

Most of the straw pulping processes currently in use in the world are outlined in the sections that follow. These sections attempt to describe each process in brief, including how some of the problems associated with straw are handled, the general qualities of the resulting pulp, and what product(s) it is best suited for. The recommendations as to what processes should be considered for use in Montana over the next few years are provided in the section, "Potential Bidders." The following is a list of issues that need to be considered in making such a selection:[4]

- The availability and location of the resource. (See the Availability Section.)

- The potential market and specific buyers to be approached. The buyers need to provide information about their specific quality requirements for the pulp, as well as some general information about their final product(s). A quantity also needs to be agreed on, as well as a price range. With quantity and quality information in mind, various pulping processes can be eliminated if they cannot meet those requirement and still be profitable. If, for example, the buyer is small, processes that require a large mill should not be considered.

- Certain processes can be eliminated if they cannot economically meet the environmental criteria set for the project. These may include water needed, effluent controls, type of chemicals used, or air emissions. Many of these criteria are discussed in the "Developing Criteria" section in the introduction to this work. Note that some processes may be suitable for use in conjunction with the Frenchtown mill since it has recovery and effluent treatment systems in place, whereas they would not be suitable for a location near Harve.

- The ultimate location of the mill. This depends on factors such as storage areas, transportation options and costs, water and energy supply, as well as available labor supply. The preprocessing equipment/center may or may not be located next to the mill. Location options could be a deciding factor for choosing a pulping process.

- Specialists to be approached it designing and building the mill. Care needs to taken that a process that has been proven in the laboratory will have similar results on a larger scale, and can be fashioned into an economical and functional mill. It is possible that some pulping options would be eliminated with this step.

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[4] Robert Hurter deserves some credit for the process outlined below. He provided me with an unpublished set of questions that he uses to assess an area's potential to use agricultural residue for paper. These questions provided significant guidance for those developed here.

- The total start-up costs may determine the final choice of the pulping process. It will take some funds to get through the previous steps. If all the steps are successful, then funding needs to be secured to complete the mill design in detail and to build it. Additional funds will be needed to cover start-up costs during the initial period of operation.

It is likely that there will be more pulping options available if straw is pulped in conjunction with the existing facilities at the Smurfit-Stone linerboard mill. On the other hand, doing so may limit the range of options for the final product type. Water needs and effluent handling are most likely the limiting factors in locating a mill in Montana's "Golden Triangle".

PULPING EQUIPMENT

BATCH VS. CONTINUOUS DIGESTERS

There is some debate as to whether batch or continuous digesters are better suited for use with straw. Even two of the most recognized experts on the subject of straw pulping differ on this issue. Atchison prefers the continuous digester and highly recommends the Pandia Digester, sold by the Pulp Biomass Technologies division of Voest-Alpine Industrieanlagenbau in Linz, Austria. This horizontal digester with a screw feeder is available in different sizes, as small as 60 tons per day (tpd), and can produce pulp in as little as 10-12 minutes. Horizontal digesters provide better mixing and are suited to open-celled agricultural fibers such as straw.

The benefits of the continuous digester include maximum uniformity in pulp, uniform consumption, uniform stream and power consumption, uniform liquor consumption, low stream requirements, relatively high capacity and yield, small space requirement and low labor requirements.

Jeyasingam, on the other hand, strongly suggests batch digesters for pulping straw. His findings show batch digesters work better than continuous digesters for straw. Due to its bulky nature, straw tends to clog up the screw feeds of continuous digesters. Once a clog occurs, the whole operation shuts down until it can be fixed. These stoppages can quickly impact productivity and profits. Batch digesters also allow more flexibility to alter chemical requirements for different moisture levels, species and consistencies of fiber.

THE TORNADO

There is some difference of opinion as to whether or how this 3000 gallon capacity fiber processor could be used in straw pulp production. Clearly it can function as part of a preprocessing system or potentially be used after pulping to replace energy inefficient beaters. The manufacturers, however, Bolton-Emerson Americas Inc., suggest that it can be used as the central unit to a nonwood pulp production system. They suggest that it can take baled agricultural fiber (or recycled fiber) and process it directly from the fields to virtually any desired consistency.

Other sources believe that the Tornado, with its extensive mechanical action, may damage straw and that the resulting fiber can be so reduced in freeness that it becomes useless for papermaking. The manufacturers counter this argument by noting that the machine is highly adjustable and can be set to minimize such damage.

In either case, it is important to note that when using the Tornado without cooking, the resulting pulp is a mechanical pulp. As such it is usable for newsprint, corrugated medium, and possibly linerboard, but not well-suited for fine papers.

THE BIVIS SCREW

Aikman discusses the possibility that the Bivis screw, developed by Clextral, a French company, is an important piece of process equipment to produce paper pulp. This machine cuts the fibers with a rotating screw. As the material is moved along the screw, chemicals are added to delignify and bleach the pulp. The Bivis combines the chopping and pulping processes, though other equipment is needed for preparation and final screening.

Clextral claims that the Bivis screw reduces caustic soda, bleaching chemicals, energy and water use. The machine is reasonably priced and has low maintenance and operation costs which make suitable for smaller mills. The pulp is of constantly high quality. It has been successfully used by Portals, in the UK, for making banknote paper from cotton. In their experiments for making straw fluting with a chemi-mechanical sulphite process, the St. Regis mill in Wales has achieved yields of 90% without silica problems..

SODA PULPING VARIATIONS

The most widespread process in current use for pulping straw is the soda pulping process. It has a number of variations. Two basic chemicals are used, NaOH and Na_2CO_3, and often oxygen or anthraquinone (AQ) are added to the process. Temperatures usually range between 140-180° C and pressure varies with the process. Soda pulping is also used in combination with other processes. The NACO, Saica and Universal processes are essentially soda processes, but are described below in their own sections.

Aravamuthanet al. look at optimizing the cooking using caustic carbonate ($NaOH-Na_2CO_3$). They find yields of 52-65%, depending on time and other constraints. Increases in Na_2CO_3 reduce cooking time. Jeyasingam finds that soda pulping in batch digesters is widely applied throughout the world. Generally soda is added equivalent to 10-12% of the dry weight of the straw. It is cooked between 140-170°C. Cooking time is reduced with higher temperatures. On average, bleached yield is 35-40%. The chemical recovery of the cooking liquor is limited by silica content.

Jeyasingam also notes three other basic soda pulping variations. In the H. F. Process (Hojbygaard Fabrik) for producing corrugated medium, straw is cooked in addition to waste paper in a simple caustic soda process that reduces the chemicals and steam needed. Both the Esher Wyss and MCP processes use caustic soda, occasionally with lime, to produce unbleached grades with a 55% yield. Cooking is not under pressure and less chemicals and steam are needed compared to pressure cooking but the digesters can have problems.

Erogluet al. studied oxygen soda pulping of straw, cornstalks, cotton, sunflower husks and other residues. The process worked on all of the residues, but straw had the highest yield. Yilmaz finds that adding oxygen to the soda process reduces the beating time on unbleached pulp. Rao et al. find significant gains in yield, strength and optical properties, and the reduction of rejects, lignin content, and Kappa with the addition of pressurized oxygen to the soda process for rice straw. Usta finds that soda oxygen pulping showed good results with the cooking of cornstalks.

Goyal et al. compared soda and soda-AQ pulping. The addition of AQ shows significant benefits including increased yield and strength, and decreased cooking time and Kappa. Many of these changes were more apparent with increased alkali charge. Cao and Lee find that .1% AQ added to the cooking liquor reduces alkali consumption 34% and reduces Kappa by 20 units. In contrast, adding 3% hydrogen peroxide increased alkali consumption 25% and had no affect on delignification. AQ delignification was also more selective.

In a comparison of a variety of pulping processes, including Organosolv, explosion/vapor, alkali-oxygen, and others, Ray finds that the soda-AQ is generally recommended. Atchison finds that most existing straw mills use soda and are switching to soda-AQ processes. AQ can either reduce cooking time or chemical levels. With its addition, cooking times can be reduced to as little as 5 minutes when using temperatures higher than 170° C or pressures higher than 100 psig.

Hultholm et al. experiment with the three step IDE process: impregnation (I), depolymerisation (D) and extraction (E). In the first step, soda (NaOH or Na_2CO_3) impregnation is used to remove 75% of the silica. They have still not found a method to remove the silica from impregnation liquor, but believe it will be easier to separate than from the black liquor (BL). In the second step, a high temperature concentration of up to 50% ethanol is mixed with water. The extraction step used an additional fresh mixture of ethanol and water. They find they could easily achieve a yield of more than 50% with lignin below 2.5%.

Montané et al. examine the use of soda in combination with an impregnation-rapid-steam-pulping (IRSP) process for straw and compared it to conventional soda pulping. Steam processing alone has yields of 80-95%, but paper properties are only comparable to chemimechanical and chemithermomechanical pulps. That process "involves chemical impregnation of the chips with aqueous solutions of $NaOH/Na_2SO_3$ at 60°C for long times (up to 24 hours), steaming at temperatures of 180-240°C for short periods (typically 4 minutes), defibration of the cooked chips by instant pressure release (steam explosion), refining, and bleaching."

Their variation of IRSP called for impregnation with 20-30% NaOH for ten minutes at 100°C. Lignin removal was up to 72% with the higher charges of NaOH, but that level began to produce degradation. After fines were removed, the yield was reduced, but pulp properties were improved, over conventional straw pulps, even with bleaching. Overall, however, the pulp did not respond as well to bleaching. Ash content was not reduced by the process. Nodes were screened out after cooking. They reported final yields of between 37-57%.

Aikman describes the alkaline, sulphite, anthraquinone and methanol (ASAM) process, developed in Germany in the early eighties. He finds many advantages to this process, including no need for chlorine, no sulfur smell, high yield and quality, and minimal effluent treatment costs. Also, it uses conventional machinery, the chemicals can easily be recovered and the process works with either batch or continuous digesters.

Eroglu and Deniz compared the predesilication of straw with NaOH, Na_2CO_3 combined with Na_2SO_4, and HF. A three stage treatment of 1% NaOH was found to work best, as it reduced silica by 73% at a very reasonable cost. HF also worked, but was found to be too corrosive, and too costly. They note other methods that succeeded in removing silica, but find that they all had problems. Some have tested the use of quick-lime on the weak black liquor to produce calcium silicate and others have successfully tested a wet air oxidation method, but the equipment for these processes is expensive. Other have tried treating the liquor with CO_2 to shift the pH above 9 so the silica precipitates out, but this method reduces thermal recovey efficiency.

THE NACO PROCESS

NACO describes its process as having a 48% yield for straw to produce an unbleached pulp with a 15-16 Kappa, and an ISO brightness between 50-52. The pulp can be ozone bleached to 75-78 ISO, or can be bleached up to 80-82 ISO with ozone then peroxide. The process is chlorine- and sulfur-free.

The straw bales go directly into process. Different size and shape of bales can be used. Contaminants are removed with a light caustic NaOH or Na_2CO_3 pretreatment for 15-20 minutes at 50° C with turbulence, which cuts the straw. A fluidification device completes the separation of dirt and sand. The silica is reduced 50% in preprocessing. The treatment also removes waxes. The pretreatment yield is 80-90%. Overly moist straw and straw up to ten years old has been processed with a lesser yield.

A special turbopulper is used for the main pulping stage. Jeyasingam noted that a chemical recovery boiler can be used to produce a sodium carbonate solution that is used directly in the turbo pulper. The straw is then washed, dewatered and pressed, yielding about 50%. Since no recausticizing plant necessary, silica abrasion is avoided and less capital is needed for recovery, which makes a small mill is possible.

The silica in the effluent is treated with lime, which reacts to form calcium silica, which is insoluble in water and removed. The lime also turns some of the Na_2CO_3 to NaOH. The pretreatment effluent is treated with an anaerobic treatment which alone satisfies most effluent requirements. The organic matter is incinerated. The gasses released from the mill are mainly CO_2, N_2 and H_2O. Generally the process is low in temperature and pressure, making it generally low maintenance.

Pulp and Paper International (PPI, 1987) notes this process was developed by Franco Nardi but Sunds Defibrator holds part of the patent. They describe the process as producing minimal pollution, and requiring minimal investment. Generally it uses soda and oxygen for pulping. The oxygen in the process helps clean the pulp and reduces power needs. The process can use ozone for bleaching to produce printing, writing and security papers. The pulp from the process is mixed with OCC and occasionally some wood pulp. They acknowledge the pulp as higher in wet strength than other pulps. They have used it to produce a magazine paper with 45% straw, 20% OCC, 20% deinked pulp, and 15% filler, which is used for Italy's official state magazine.

The preprocessing system used is considered a wet cleaning, which reduces the risks of dust and fire. This pretreatment removes silica, wax and other contaminants. The process is described as more like delignification than cooking. Nardi believes the proper definition is cellulative wet combustion. The total pulping time is 1.5 hours and water use is 15 m^3/ton of pulp. In 1986, the recovery system cost $8/ton of pulp.

Croon notes that the NACO pulping process is sulfur-free, TCF and almost closed-loop, produces a pulp bleached to high brightness.

SAICA'S PULPING PROCESS

Marcus gives a detailed description of the Saica process. He reports the Spanish Company, Sociedad Anónima Industrias Celulosa Aragonesa (Saica), as the world's largest straw pulp and paper maker. They use on average 600 tpd (~220,000 tpy) of straw at one mill, with additional production expected at a second mill. They generally make fluting (corrugated medium) with 20-50% straw find that it increases stiffness. They've found that it is possible to make 100% straw fluting, but these higher percentages are harder to run in the papermaking machines.

The straw usually comes from within a 75 mile radius, but during drought it must be imported from as far as 150 miles. It is stored in 800-1000 ton super-bales, and can be stored up to three years if baled dry. Only the outer 4-5 inches is effected by the weather. The mill keeps a two day working supply in a covered area, which is equipped with a sprinkler system in case of fire, of if the straw needs moistening.

First the straw is cut and "bruised" to improve chemical treatment. Jeyasingam believes that the mechanical action needed to defiber the pulp reduces its strength. It is then moved by conveyers with magnetic traps to remove metal contaminants. Croon believes they use 5% aqueous sodium hydroxide on oven dry straw. They have four independent digesters each with 100 tpd capacity, that also serve as counter-current washers. These are of a special design and marketed by Straw Pulping Technologies.

The straw is cooked for 2.5 hours at 100°C and atmospheric pressure which eliminates the need for a blow tank. On average they achieve a 62% yield, using 52.5 kg of caustic soda, 170 kW of electricity, 0.55 tons steam, 4.3 m^3 of process water, and only 1.2 m^3 of fresh water for each ton of pulp.

They feel that the size of the mill makes chemical recovery uneconomical. Some of the effluent from the pulping process is used to pre-impregnate the next batch. The rest is pumped out and mixed with the rest of the mill's effluent. The effluent is first sent through an electrostactic filter to remove dust and particles and then treated aerobically for seven days. That, Marcus reports, "is followed by clarification, aeration, flocculation and centrifugal mixing of the sludges with the rejects from the wastepaper lines. The resulting mix is then dewatered and passed through a screw press from which solid waste is trucked away to disposal." Methane collected from the process provides 20% of the mill's total fuel.

UNIVERSAL PULPING

Byrd, Prior and Snyder describe the two stage mild acid and alkali process developed by Universal Pulping. The first stage involves a nitric acid (HNO_3) treatment of between 0.5-1.5% in the liquor. Alum ($Al_2(SO_4)_2$) is added as accelerant for the process. Cooking takes place at atmospheric pressure, takes 20-60 minutes, with temperatures kept at 80°C. The second stage involves a mild alkaline extraction, using a 5-15% dose of NaOH on oven dry (OD) fiber. In this stage, the temperature is kept to 95° C and at atmospheric pressure for 20-60 minutes.

Overall the process needs minimal capital, in part because no pressure vessels are needed, and low in chemical usage with high chemical recycling. The pulp is bleachable to 80 ISO after two stages of 4% peroxide with DTPA chelation, and the bleached pulp has good strength, freeness and viscosity. The combined acid/alkaline effluents can produce a land spreadable byproduct. The biggest drawback is low yield, which is only about 30%,. The chemical recovery methods are not made clear in the literature, although it appears that the silica is largely distributed between pulp and alkaline liquor.

Universal pulping notes that, "Utilization of black liquor that resulted from the two-stage acid/alkaline cooking process was absorbed in the board production with waste paper fiber. It was found that the liquor, with additives, could be modified and applied at the paper machine size press, enhancing board qualities of color, size and mullen, while also providing mass in place of fiber. Such improvements reduced the cost of pulp by one third. The two-stage, acid/alkaline process will produce an easily bleachable pulp and allow for the easy separation of the hemicellulose-lignin solution (black liquor, inter-fermentable sugars and lignin). The lignin-hemicellulose byproduct solution is non-toxic, non-malodorous and can be fractionated, modified and fermented to produce numerous value-added products."

POTASSIUM PULPING

Wong discusses potassium pulping in numerous articles and employs this process in Arbokem's working mill in Alberta, Canada. He finds that potassium (K) is chemically very similar to sodium (Na) at least in pulping operations, and that potassium pulping is chemically similar to soda pulping. Unwanted silica remains a problem in a potassium-based straw mill. (See Figures 8 & 9, pages F-13 & F-14 for a general outline of the Arbokem process.)

Aikman notes that potassium-based pulping has been used for more than fifty years. Some have even proposed a potassium pulping for wood. Ruf has noted that potassium can create problems in kraft mills which are attempting to head towards minimum effluent. The potassium will gradually build up in the sodium, making recovery processes difficult. This can be solved by moving to potassium pulping instead of soda. The use of KOH instead of NaOH requires only minor changes in the mill operation. potassium and sodium based pulping also proved similar in experiments at the Corvallis, Oregon, Forest Products Laboratory. Aikman believes potassium pulping is high yield and produces a pulp with high tear strength.

The naturally-occurring potassium in straw is 1-3% by weight, compared to less than 0.1% in wood. The natural potassium in ag-fibers can build up in a pulping system that attempts to be low or no effluent. In kraft operation for nonwoods, the potassium will reduce recovery boiler heat and efficiency. Boilers could be redesigned to handle the new chemical balance, but that is expensive. The natural potassium is not a big problem in ammonium (NH_4OH or NH_4SO_3) or potassium-based pulp mill, but ammonium based pulping has low brightness.

In contrast, potassium pulping has much higher brightness and can result in a potassium-based fertilizer. Wong, Krzywanski and Chui look at using potassium for a 5000-15,000 tpy closed-cycle mill, which would produce intentional solid byproducts rather than releasing effluent. They expect to use the effluent to make a liquid or solid fertilizer containing potassium chloride and sulphate. It would be good for rice, tobacco, citrus fruit, tea, sugar cane, coffee, cocoa, rubber, palm oil, and potatoes.

The Arbokem mill designed by Wong in Vulcan, Alberta, started production on July, 29, 1994. It has at least a 2,500 tpy capacity and uses KOH and K_2SO_3 along with water and steam for pulping and peroxide for bleaching. The effluent is evaporated and can be used as a soil additive, although the cost effectiveness of dehydrating the effluent and the sales potential as a soil additives are still in question. Still, Wong sees profits coming from small a well-run straw mill when the market price of pulp is about $400/ton.

AMMONIUM AND UREA PULPING

Aikman notes that sodium hydroxide can be replaced with ammonium sulphate. This process is used in China at more than 20 mills where the spent pulping liquor is used for valuable fertilizers. Aikman also notes Chinese and Indian experiments using urea or ammonium compounds for pulping. These experiments found reduced pulping cost and pollution. However, Aikman also cites Kishore (1990) who finds pulp quality required 8% urea comparable to pulp produced by only 4% sodium hydroxide. The urea straw pulp was only good for low grade brown packaging.

SOLVENT PULPING

The numerous variations of solvent based pulping are sometime used in combination, or as pretreatment for other pulping processes. Schroeter lists 17 different solvent processes, and describes some including Alcell® (water and ethanol), Acetocell (acetic acid), Milox (formic acid and peroxide), Organosolv (methanol alkali and anthraquinone) and ASAM (alkali-sulphite-anthraquinone-methanol). There is some skepticism about the cost-effectiveness of solvent based pulping. Kurdin notes that although the solvent process has been around 50 years in different incarnations, but thinks that it will never get off the ground.[5]

Aikman notes that generally the alcohol used in each process can be easily recovered and reused. He finds, "Alcohol processes are generally considered to be: clean technology, since the pulping agent is recovered by distillation, not by burning, an innocuous effluent is produced; more productive with increased fibre yield and strength; more suited to a smaller scale; expensive, but expense can be offset by production of a high value pulp, recovery of alcohol and sale of by-products."

ORGANOSOLV

The Organosolv process was developed in 1931 by Kleinert. In a comparison of various solvent processes, Schroeter finds the Organosolv process to have low odor, no difficult effluent to treat, a cost effective recovery system and good pulp properties.

El-Sakhawy et al. experimented with the use of Organosolv pulping with aqueous ethanol and other additives followed by alkali ethanol in an attempt to minimize chemical use and time while maximizing yield and quality. They found the best results were achieved with the addition of anthraquinone, which generally resulted in a 56% yield and chlorine numbers between 3 and 15. The reaction rate doubled as the alkali concentration doubled and increased directly with temperature.

The process was fast and selective under mild conditions, even with extended cooking times. Above 160° C and with higher alkali concentrations (0.6 mol/L) selectivity was lowered. El-Sakhawy et al. found that wheat straw was easy to delignify with this process, even with lower reaction energy and less time. They had good results (55% yield) at alkali concentrations of 0.3

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[5] From a telephone conversation on 12-22-98.

mol/L and cooking for an hour or less at temperatures of 120-140 degrees. Cooking time can be reduced to as little as 15 minutes.

AQUASOLV

The Aquasolv process was introduced in 1968. Spencer, Allen and Antal find that it possesses potential for use in dissolving straw pulps. Aquasolv dissolves practically all of the hemicellulose and much of the lignin. This reduces total yield, but allows for the products to be separated into potentially salable byproducts. The remaining pulp (after treatment has removed hemicellulose and most of the lignin) does not suffer from the remaining lignin. Further refinement of the pulp with alkaline extraction and peroxide could produce dissolving pulps.

ORGANOSOLV COMBINED WITH AQUASOLV

Kubikova et al. examine hydrothermal pretreatment of straw using Organosolv and Aquasolv. They find that the best results came from combining the two methods. Koullas looked at using aqueous and Organosolv treatments to remove lignin and convert the lignin to fuel through carbonization for charcoal.

ALCELL®

Winner describes the Alcell® process, owned by Repap Enterprises, as "autocatalyzed alcohol." It has been used commercially on hardwoods and studied for use with bagasse and kenaf. It is recognized for its potential to pulp straw because it is suitable for smaller mills. The Alcell® pulp was readily bleached by either ECF or TCF processes and the bleached pulp from kenaf was comparable to conventional hardwoods. Lignin can easily be recovered from the cooking process to produce salable byproducts including lignin, xylose and furfural. Paper Technology notes Repap's claim that the Alcell® process produces an "environmentally acceptable" effluent and that the process can work on a relatively small scale. The co-products, including lignin, xylose, and furfural, give the process a market value twice that of pulp alone.

FORMIC ACID/MILOX PULPING

Much of the experimentation using formic acid for pulping used reeds, but general experience indicates that it could work for straw with minor modifications. Reeds share the silica problem with straw. Formic acid pulping is expected to have profitable by-products including lignin, other extractives and nutrients.

Seisto describes the Milox two stage process. The first stage uses formic acid alone. The second uses formic acid with peroxide. It is believed that Milox pulping can share a wood based recovery system, as the silica remains in the pulp rather than bleeding into the effluent. Some silica is acceptable in the pulp or in the papermaking process. The silica can also be removed during bleaching, in which chelation is used before 2-3 stages of peroxide and achieves high brightness.

Rousu also examines using formic acid to pulp reed. He finds that using formic acid with oxygen followed by peroxide bleaching can attain better than 90 ISO brightness in nonwoods. He also finds that silica does not dissolve into the liquor during the pulping process. The silica becomes sodium silicate in alkali bleaching conditions and can be removed. His results also indicate that a closed-loop system is possible with this process, because effluents can be purified and recirculated. This also reduces chemical use and costs.

The objectives of Rousu's study were to develop a small mill of less than 450 tpd (160,000 tpy) that produce a high brightness pulp. Interestingly, the brightness from the bleached grass actually has a greater than proportional influence on the total brightness in a mix with bleached pine and aspen pulps. The mill would need a simple, economical closed-loop recovery system and no use of chlorine or sulfur. Some metals and nutrients would be returned to the fields as fertilizer. An feasibility study for such a mill in Finland that is located near an abundant source of reeds shows that 500 tpd of pulp is the minimum required to reach the profitability.

SEMI-MECHANICAL AND SEMI-CHEMICAL PULPING

Ray, Mathur, Varma and Garceau find that mechanical pulping can improve yield over conventional soda pulping and reduce the pollution load. They experimented to find the ideal conditions for temperature, cooking time, liquor consistency, and alkali dose.

Jeyasingam (1986) emphasizes that you can't simply follow wood-based pulping practices for straw. He finds pressure cooking is preferred for straw to reduce fines. He also suggests defibration before washing and finds the simple decker type to work best. He recommends three simple pulping systems and notes that high yields are necessary for corrugated medium to remain competitive.

The first system has nyblad straw cutters, a spherical batch digester, a Tornado pulper, a conical refiner, and a flat screen system. This system produces an overall yield of 60-65%. He also identifies (1988) a sulfur-free, lime (CaO) based pulping process with virtually no effluent that is good for corrugated medium and linerboard. The pulping heats the lime to 130-140° C for 3-5 hours. The final mechano-chemical process uses a hydropulper with caustic soda, with the possible addition of sodium sulfite. This system requires only a small low investment and produces a high yield of 70-79%, but requires high chemical, steam and power consumption.

Kurdin recommends Alkali Peroxide Mechanical Pulping (APMP) developed by Quantel Engineering of Calgary. This process, sometimes called 'cold soda,' is basically mechanical. Because the lignin is not removed yields are higher. "The process results in carboxylation of lignin with oxidants... [which] results in lignin with carboxylate groups, which are capable of participating in hydrogen bonding, increasing fiber bonding in paper making."

The chemicals remaining from the second pulping stage are used to impregnated the material during the initial stage. The process produces only small amounts of effluent that can be treated in conventional systems. Since there is no chemical recovery, silica is not a problem. This process produces a bleachable pulp, which is typically done with peroxide. Chelates can be used to improve peroxide efficiency.

Aikman also discusses APMP as a process that could potentially produce a bleachable pulp that is primarily suited for coated or uncoated printing grade papers or for newsprint. He also notes that varying the amount of caustic affects the bonding strength and scattering coefficient (surface area) of the paper. Typically the pulp would be blended with wood pulp to improve strength

NEUTRAL SULFITE PULPING

Ali et al. find that a neutral sulfite batch pulping using Nyblad dry cleaning method produced a high yield, easily bleachable pulp. The yield was even higher than soda or kraft pulping, as both of those processes extract more of the hemicellulose than neutral sulfite. The yields ranged from 50 to 90%, but were generally around 60%. Yield depended on sodium sulfite dosage which typically varied between 10-15%. The pulp showed improved tear, burst, tensile, yield and was bleachable by a CEH[6] sequence. The pulp showed increased smoothness, opacity, and interfiber bonding in paper, due to leaner fibers and high fine content.

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[6] C=Chlorine, E=Extraction, H=Hypochlorite.

Tian Hongguang and Cao Guangrui describe their research on neutral sulfite pulping, which has been used commercially since the 1940's. They find that pulping at 160-170°C rapidly removed about 2/3 of the lignin, but the remaining lignin proved difficult to remove.

SULFATE (KRAFT) PULPING

Paavilainen and Tulppala investigated the use of sulfate (kraft) pulping using reed canary grass in a pilot process, which was eventually to be integrated into a mill using both softwood and hardwoods. They used air cleaning, the mechanical action of which increased drainage and bleachability. The pulp was bleachable to 89 ISO with an ECF (chlorine dioxide) process. They find that to be competitive with wood, the costs to mill gate had to be slightly less that those of wood: $88 vs. $93-104.

Jeyasingam, however, finds the kraft batch pulping of straw more expensive than soda. Kraft straw pulp also has reduced strength compared with soda. An effective effluent treatment is also required for kraft pulp and the yield is only 35-40%.

STEAM EXPLOSION PRETREATMENT

Montané et al. look at steam explosion pretreatment of straw followed by alkali pulping. They find that the lignin removed from the straw increases with the severity of treatment, and predict that the process could create potentially marketable hemicellulose and lignin byproducts. (See Figure 3, page F-9.)

Lawther uses a 120° C with 2 bar pressure steam treatment to carefully characterize the various chemical components of the straw. The various phenolic acids and aldehydes found include gallic acid, protocatechuic acid, p-hydroxybenzoic acid, p-hydroxybenzaldehyde, vanillic acid, vanillin, syringic acid, p-Coumaric acid, syringaldehyde, and cinnamic acid. Many of these could be salable byproducts, but as of yet their extraction has not yet been proven to be economical.

Richard and D'Agostino of Stake Technology Ltd., developed a high pressure, low temperature steam explosion treatment that they claim produces stronger pulps with higher yields and uses less chemicals, which does not need chemical recovery. They suggest that there is no commercially viable way to remove silica from black liquor. Using the steam treatment, silica is generally not solubilized after explosion, so it will remain in the pulp and actually improved its stiffness. They use a C0-Ax Feeder to compress the fiber and a Stake II Digester, which is chemically charged with 8% sodium sulfite and 1% sodium hydroxide, and then "explodes" the pulped mixture to atmospheric pressure. They claim the system is 95% energy efficient.

FUNGAL, ENZYMATIC AND BIOLOGICAL PULPING

Experimentation is in progress to use fungal, enzymatic and biological treatments to either pulp fiber or to improve various pulping and bleaching processes for use with both wood and nonwoods. The goal of the research is to reduce chemical and energy consumption. Aikman notes the potential of these new treatments to reduce effluent loads. Although these treatments are not widely used, they deserve consideration, as many could make straw pulping more economical.

Bostanci experiments with the use of oyster mushrooms, part of the "white rot" fungi group, to degrade various non-cellulose components in fiber. Part of the experiment is to determine which inoculation period produces the best results.

Giovannozzi-Sermanni et al, experiment with the use of enzymes, in conjunction with a special pressure treatment. The straw is first put through a dry mechanical chipping in rotating chipper to remove pith, soil, dust, weeds, seeds, pebbles etc.. This resulted in a preprocessing yield of 85-94%. The straw is then hypercompaction-pressed to 500-1000 kPa to reduce air and induce permanent modification to the plant structure. The press increased fiber density from 100-300 kg/m^3 to over 1000 kg/m^3 (approx. 60 lb/cu. ft.). Various enzymes were tested to pretreat the straw before pulping in a continuous digester for 95° for 30 minutes. Some enzymes reduced hemicellulose. Generally the pretreatment reduced alkali requirements by 40%, and energy requirements by 20%.

In another experiment, Giovannozzi-Sermanni et al. used a biological pretreatment with lentinus edodes, a lignolytic enzyme. After biodegrading for 20-30 days, the pulp showed higher tensile and burst strength and better fold properties after beating. Breaking and burst length are initially reduced by biotreatment but recover with beating. The pretreatment reduces the refining needs by

50% because the lignin becomes easier to remove, reducing chemical demand. It also reduces energy needs by lowering beating times. They find that even short treatments (hours) could reduce beating times. Pretreatment is stopped before the mycelial grow stage, which reduces yield.

CHEMICAL RECOVERY

The silica present in straw averages 6% by weight. In many pulping processes, including kraft and soda (alkali), silica builds up in the black liquor. In most processes, the black liquor is sent to a recovery boiler. The build-up of silica in a recovery boiler lowers its efficiency, and in some cases, makes chemical recovery impossible.

The slow drainage of straw and also affects the recovery operations. Operations using standard pulp washing equipment often must increase the dilution of the liquor, making recovery less efficient. Slow drainage also slow the dewatering of the pulp. It is a bit of a myth that there is no way to deal with these problems. Processes designed to mitigate the problems associated with the chemical recovery in straw pulping are described below.

CHEMICAL RECOVERY IN THE KRAFT PULPING OF STRAW

AghaMohammadi, Durai-Swamy and Das explore chemical recovery options in a kraft mill that used an addition of potassium for nonwood pulping. They find that an MTCI Indirect Gasification System can also be used to recover potassium and other pulping chemicals. The system is also used to collect a Btu-rich fuel which can be used to energize the process. The system is designed for plants pulping with a kraft process but may be tailored for use with other processes.

Välttilä, Jaarmo and Järvinen investigate silica removal from bleach plant effluents. Silica is introduced via the lime used in the recaustizication process used to make white liquor. Magnesium, aluminum and calcium are employed as coprecipitants to remove silica in a bleached kraft process that is attempting to move towards a closed-loop system. Magnesium was found to be the most effective coprecipitant. Various other elements are removed through this process as well. This process may have some applications in nonwood pulping and bleaching.

CHEMICAL RECOVERY IN THE ALKALI PULPING OF STRAW

Chaudhuri explores the problem of silica removal problem in an alkali-caustic soda pulping process. He finds that the use of a counter current pulping kept the silica from getting readsorbed in either the pulp or the black liquor. The Spanish Saica and Danish Hojbygaard mills are noted as effective pioneers in the counter current cooking and washing of pulp. The washing stage is a critical first step for efficient effluent recovery. A critical element in effective recovery is minimizing the dilution of the liquor during pulp washing. The rotary vacuum washers used for wood are not suitable for efficient washing of the relatively slow-draining straw pulp.

Mevawala and Basu propose using a multimedia sand filtration, two-stage carbon filtration, nanofiltration process, coupled with electrodialysis to recover soda. The process was found to recover 55-60% of the soda. Further experimentation and in-plant pilot trials are recommended to evaluate the technical and economic feasibility of this process.

Rangan and Rangamannar explore three recovery options for managing the silica problem in soda pulping processes of small mills which use agricultural residue feedstock which include ferrite, indirect gasification, and desilication with conventional recovery.

1) The ferrite process is suitable for soda pulping and has operated on pilot scale in Denmark. A dust recovery system is necessary. It is a direct alkali recovery system (DARS) using the following process:

Combustion:
$BL + Fe_2O_3 \longrightarrow Na_2Fe_2O_4$
Leaching:
$Na_2Fe_2O_4 \longrightarrow NaOH + Fe_2O_3 + Heat$
Most of the silica remains with the hematite and must be occasionally purged out.

2) Indirect gasification takes place in thermochemical conversion reactor (TCCR). It can process black liquor with up to 30% solids to produce a residue of 98% Na_2CO_3 in the form of a dry powder. The process uses a fuel gas that is a mix of H_2 (50-60%), CO (5-10%), CO_2 (20-30%), and CH (2-10%). The silica present in the liquor remains as free silica in a fluidised bed reactor. A demonstration pilot plant was installed by Esvin Technologies (Licensee of MTCI, USA) in an Indian mill. A plant using this process can be scaled to size, starting at a lower end of 10,000 tpy.

3) A pilot system using desilication & conventional recovery was installed at Hindustan Newsprint. It was developed by CPPRI and is marketed by a company at Chennai. The pilot plant shows, "It is possible to get more than 90% desilication without precipitation of organic matter. Silica sludge may be use in by-products to make the process more attractive economically." Further refinements of the process are expected to occur.

CHEMICAL RECOVERY IN THE KRAFT PULPING AND ALKALI PULPING OF STRAW

El-Shall and Cooper report a process which separates lignin and silica from spent liquor that is usable in either by soda or kraft pulping processes. A polymer surfactant treatment is applied to the liquor, followed by acidification. Silica and lignin float to the surface in agglomerated clumps that can by easily separated from the remaining clear liquor. For a kraft process it also works as an alternative recovery system to an overloaded recovery boiler. The process seems to work best in soda pulping processes of vegetable fibers. The equipment and reagents are inexpensive and currently available on the market.

Kappel explores the use of the double wire press for washing nonwood pulps. Both wheat and rice straw have notoriously difficult drainage problems. This special unit designed in part by UNIDO dewaters pulp in a vertical cylindrical vessel with piston moving upwards from the bottom. He finds it more effective than standard washing systems.

BLEACHING

In some respects it is easier to bleach straw than wood, although in other respects it more difficult. Straw starts with less lignin, and a cell structure that binds the lignin less tightly than wood. This makes removing the bulk of the lignin a less chemical and energy intensive than delignifying wood pulp.

The difficulties occur in bleaching straw pulp to high brightness. For both straw and wood, the pulping process removes some of the lignin. Straw pulp tends to be significantly lighter than wood pulp even without bleaching. After pulping a variety of chemicals and catalysts can be used to remove more lignin. Traditionally these chemicals have included gaseous chlorine and chlorine dioxide, and hypochlorite.[7] More recently, pressurized oxygen, ozone, and hydrogen peroxide are employed.

The chemicals used to bleach either wood and straw can affect fiber quality. Damage is greater with increases in quantity or concentration of the chemical, and with certain temperatures and pressure conditions. Damage can occur more easily with straw and have a greater overall impact on the quality of straw pulp due to straw's shorter fibers and more open cell structure.

Careful chemical and process controls can minimize damage to the fiber for both straw and wood during bleaching. Minimizing damage is increasingly difficult as a higher brightness is desired. For both wood and straw, chelates are often added in the initial stages of bleaching to reduce the quantity of metals in the fiber. Metals react with the bleaching chemicals, particularly ozone and peroxide, in such a way as to magnify the damage to the fibers.

Pekarovicova, Jameel and Joyce experiment with various TCF bleaching processes using straw pulped with a modified Organocell process. Their modification omitted the streaming before cooking. The processes includes O-L-P, O-X-P, O-P, Eop-X-P, Eop-L-P, and X-Q-P.[8] The O-L-P and X-Q-P processes obtained 73% and 82% ISO brightness respectively, for a pulp starting at Kappa of 10 and 42 ISO brightness. They generally found the pulp to have good characteristics for writing and printing papers.

A study by Abdul-Karim and Rab (1978) investigates optimizing oxygen bleaching of wheat straw cellulose. Attempts are made to find the ideal conditions to control the reaction to prevent undesirable carbohydrate degradation. They find, "Oxygen bleached pulp from wheat straw meets the requirements necessary as a raw material for the production of bleached cellulose."

They use an alkali for dissolved pulp with an oxygen based bleaching process which includes an additional magnesium sulfate charge. The pulp had a starting Kappa of 17 (29 % brightness), Freeness 31, Tear 5.51, Tensile 73.5, and Burst 5.5. They also find an ideal opacity results from a 2% alkali charge which gives the pulp an 11 kappa (33 % brightness), Freeness 27, Tear 6.68, Tensile 73.5, and Burst 5.27.

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[7] Since chlorine and hypochlorite are being outlawed by the EPA as bleaching chemicals, research involved in bleaching with these chemicals will not be discussed in this work.

[8] Pulping processes are typically abbreviated using a system where each letter signifies a chemical used in bleaching, and the separation of different stages are indicated with a dash. O=Oxygen, L=Ligninase, P=Peroxide, X=Xylanase, Z=Ozone, E=Extraction, A=Acidification and Q=Chelation. Letters in lower case refer to chemicals used in lesser quantities during that stage of the process.

A second study by Abdul-Karim et al. (1977) experiments with straw using a alkali pulping process and a P-P-E-A bleaching process. The extraction is an alkali extraction using NaOH and the acidification using 98% H_2SO_4. This process may be used for a dissolving pulp for cellulose derivatives. This study does not specify brightness levels obtained; however, dissolving pulps of this type generally do obtain high brightness.

The study notes that peroxide bleaching largely tends to de-color but not remove lignin. The study focuses on maximizing yields, which ranged from 28 to 36% for bleached pulp and from 33 to 60% for unbleached pulp. Temperature, percent alkali, and cooking time, respectively, were found to have the greatest affect on bleached yields.

EFFLUENT HANDLING

There is not much in the literature devoted specifically to the problems of handling effluent from straw pulp mills. Many articles discuss the issue in brief, and raise similar issues. A common theme is to note that most of the small mills in China and many in India have little or no effluent treatment systems. The environmental problems from this effluent are becoming an issue for both countries, and regulations are rapidly becoming more stringent in India. In the US, a mill could not simply discharge untreated effluent.

The cost of an effluent treatment system for a small mill can end up being a significant percentage of the total costs. Wong notes that the disposal of sodium pulping liquor onto farm land is practiced in some countries, but sodium is of limited value as an agronomic supplement. Many suggest that this problem can be avoided by using ammonia or potassium pulping. In these processes, the effluent could potentially made into fertilizer. Xiang explores alternative disposal of effluent from an ammonium sulfite pulping process. A system using the effluent for direct irrigation and fertilization is found to be an option.[9] Two problems exist with this option: demand is seasonal and it is dubious if this would to be allowed in the US, although it is a possibility with careful testing.

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[9] Xiang also believes the effluent can be used as a base for an adhesive, but does not explore the concept further,

At the Vulcan mill, Wong also explores using the effluent from potassium pulping as fertilizer. The costs of doing so needs to be explored further, because it is difficult to dehydrate the effluent economically so that it can be transported to areas where it is needed most. This option should still be considered fully. Even if the effluent can not be used to profitably produce a fertilizer, if the losses from such a process can be kept to a minimum, overall it may still be considered an effective effluent "treatment system," and minimize environmental concerns. These effluents also need further testing for their chemical content, and their effectiveness as a fertilizer.

McKean notes that although potassium is not needed in large quantities to produce cereal grains, but is needed for potatoes and other crops[10] He is attempting to find effective straw pulping chemicals that produce an effluent that could be used to fertilize cereal grains.

The effluent from straw pulped in a kraft process is similar in composition to that created by the kraft pulping of wood, although generally it has less lignin and other solids and less chemicals per ton of pulp produced. If a straw pulping line is incorporated into a kraft mill with a modern effluent handling system, the effluents should not be an issue, with the exception of the high silica content. The effluent from a soda pulping process can also be handled by a modern treatment facility. It is likely that with some adjustments a modern treatment system could handle the effluent from straw that is pulped with an ammonia or potassium pulping process.

COMPARING THE ECONOMICS OF STRAWBOARD TO STRAW PAPER

Before making final conclusions about the potential for using Montana's straw for paper products, it is imperative to compare it to using it in strawboard products. In North America, numerous strawboard operations are already in various stages of design, financing, construction, or production. Clearly strawboard is developing more rapidly than straw paper, but why?

The reasons are basic. Strawboard mills can be smaller than straw pulp mills. Strawboard mills use as little as 10,000 tons of straw per year, compared to a minimum of least 30,000 tons and usually more for the smallest straw pulp mill. A small mill is closer to its raw material source, reducing transportation cost. Smaller mills also have less potential to stress soils, because they use a smaller percentage of straw from their sourcing areas.

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[10] Personal interview at the University of Washington, March 1998.

Smaller mills also cost less to build. Although there are a few large strawboard mills in the works, smaller mills can be built for as little as $15 million, compared with a minimum investment of $30-40 million to start a straw pulp mill, without the additional investment for a paper machine.

Another issue is product strength and quality. There are only a few paper products that can currently be made from 100% straw and meet typical US standards. In other paper products straw can replace only a percentage of wood fiber. In contrast, the wheat straw pressboard produced by PrimeBoard of North Dakota for furniture manufacturing has proven to be stronger and more water resistant than comparably-priced wood pressboard. Strawboard is also typically lighter than wood-based boards.

Finally, as with wood, straw used for board products has a much higher yield than that used for paper. Straw for board does have to be cleaned and depithed, but yields can be higher than 90%. In contrast, the highest yield for straw paper products is close to 70% for mechanically ground straw pulp. Yield from bleached pulp production can be as low as 30%, and for unbleached it is typically 50%. Higher yields thus also allow for smaller sourcing areas or less soil stress on a similar sized area than paper production.

The advantages of strawboard over straw paper make one question why bother with looking at straw paper. Once again, the answer is simple. Although growing, the market niche for strawboard has limits, and with the rapid influx of new strawboard mills, the competition could grow just as quickly. The general paper market, on the other hand, has been growing steadily, as has the niche market for nonwood paper. Further, some companies, especially those that do not own much timber lands, or which depend on nation forests for much of their raw material, are facing potential shortages for mills. Those companies include the Smurfit-Stone Container Corporation.

In Montana, the expected groundbreaking of the BioGold strawboard mill will provide a testing ground for many of the issues surrounding straw storage, handling, transportation, and the effects on the soil of residue collection. These will help clarify some of the economic questions surrounding the profit potential of straw paper.

POTENTIAL MARKETS

Clearly there are two basic possible markets for using Montana's straw in paper production: local use at the Frenchtown mill, or the export of market pulp for use in other products. These options are not mutually exclusive. Pulp for the Frenchtown mill could either be produced at the mill or near the source. Market pulp could be sent to mills producing corrugated medium, linerboard, newsprint, printing or writing papers, or other products.

Pulp for corrugated medium or linerboard is the easiest and least expensive to produce, However, both of these products are already extensively produced with recycled materials, and the market for them is currently weak. An unbleached pulp brings less of a premium, making the costs of long distance transport an issue. Some have proposed using straw for disposable products, but not much has been published on this idea.

Atchison sees straw becoming a major component of newsprint. Newsprint only needs to be bleached to a medium brightness, which bleached straw can easily achieve. It is also difficult to find a high quality newsprint with a high percentage of recycled content. In a blend with either recycled or wood pulp, or a combination of the two, straw pulp can improve the overall quality of newsprint.

Straw pulp's smoothness and opacity gives it qualities that can be advantageous to producing newsprint. Newsprint produced at Smurfit's Oregon mill using straw pulp from the Arbokem mill was successfully tested in runs by major newspapers. In limited percentages, straw pulp has also proven successful in producing printing and writing papers. Its smoothness and opacity can also be an advantage in these products.

Hurter developed a set of questions to be used in exploring the feasibility of a small new straw mill. He emphasized the importance of having an established market and a secure long-term contract for the pulp before mill construction begins. This would require agreement on the industry-accepted technical specifications that the pulp must meet. Sufficient testing would have to be done to insure that the mill could meet those specifications. In addition each shipment would have to be tested before being sent to the buyer to insure consistent quality. The contract would also have to include provisions as to quantity, delivery schedule, and selling price.

More effort is needed to find potential buyers. They should be sought from two potential categories. There are a number of paper companies that have made some level of commitment to producing environmentally benign specialty papers. These companies could be approached to consider producing products with straw pulp in the mix. Due to some limited advantages of using nonwoods in the market, they might consider a pulp that was more expensive or of slightly lesser quality than wood pulp. Other companies are facing limited supplies of raw materials, as least for certain mills. These companies would have to be approached with a pulp that is competitive in price and meets industry standards.

COST OVERVIEW

Stumborg's study in Canada finds that the total values from the sale of straw and chaff could improve a grower's income from 58-113% over the income from grain alone. Clearly, with straw paper production, a farmer can increase profits from the sale of their straw and could earn even more income from baling their own or their neighbor's straw. Consider a 1000 acre wheat growing operation. Estimating production at one ton per acre, if one quarter of the straw is sold every year for $20/ton, the total sale would provide $5000 in additional income. If the farmer bales that straw, it could provide an additional $5000, minus expenses for gas and equipment. If the farmer is part of a cooperative that invested in a successful straw mill, their long-term income could be further supplemented.

COMPARATIVE STRAW MILL COSTS

The costs tables below are initial estimates, provided only to give the reader a basis to begin visualizing the economics for straw pulping. The high figures are inflated to insure a conservative estimate. A MUCH FULLER AND MORE DETAILED ECONOMIC ANALYSIS SHOULD BE DONE BY A SPECIALIST AFTER A SPECIFIC MILL PROPOSAL IS DEVELOPED AND BEFORE ANY SIGNIFICANT INVESTMENTS ARE MADE.

Costs of a New Straw Mill Located Near the Supply

These preliminary estimates for the costs of a new 20,000 tpy straw bleached pulp mill assume straw costs of between $15-25 and baling costs of $15-25. It assumes straw will be transported up to 60 miles, but on average 20-30 miles, usually in one transportation segment at a cost of between $15-20. Handling costs are included in the transport estimates. About half of the straw would be stored near the mill and about half by the growers. Storage would either be under tarps or uncovered. Other preprocessing costs are figured at $20-25/ton. The total estimate of costs from field through the preprocessing stage are between $65-95/ton.

They also assume indoor storage with a rock floor for all months except July and August at a cost of between $7-15/ton, and outdoor storage between $0.50-1.50/ton. Some tarped storage at $3/ton at the preprocessing facility could also occur. They figure additional costs for maintenance and repair at $1.50/ton, electric power at $1.15/ton, and taxes and insurance at $1.00/ton. Total costs from field to preprocessing would average $33-42/ton, or from $4.2-5.3 million for 125,000 tons of straw. They estimate the total investment for preprocessing equipment to be $13.5-22.2 million for a mill of that size. They estimate the total cost of transporting the straw to the mill gate to be $42-58/ton.

TABLE 3
COMPARATIVE STRAW MILL COSTS: PRELIMINARY HIGH ESTIMATE BASED ON 40,000 TPY OF STRAW PRODUCING 20,000 TPY OF PULP

	New Straw Mill	SSCC	Weyerhaeuser
Cost of Straw	$25	$25	$05
Baling	$25	$25	$25
Transport	$20	$60	$25
Preprocessing	$25	$25	$25
Costs to mill	$95	$135	$80
At 50% Yield	$190	$270	$160
Pulping	$50	$50	$50
Bleaching	$60		
Mill Labor	$50	$50	$50
Pulp trans. to Mill	$15-100	$05	$15
Loans and upkeep	$300	$300	$300
TOTAL	$665-750	$675	$575
TOTAL LESS INVESTMENT	$365-450	$375	$275

The figures in the tables are inflated to account for unexpected costs. The costs for pulping and investments internal to the mill have not been released by Weyerhaeuser. These figures have been estimated from the information available. A $5-30 million investment in pulping equipment is assumed for each 20,000 tpy of pulp. It assumes 10 year loans at 7% interest and includes additional expenses for upkeep. Pulping costs are based on ranges found in the literature. The high figures very are conservative.

Estimates in the literature project the of the cost of a 20,000 tpy straw mill to be between $12-40 million. Most of those estimates include some preprocessing costs. Weyerhaeuser predicted an additional investment of $13-22 million for preprocessing and storage for a facility about three times that size. O'Brien sees L1000 (appox. $1600) per ton of capacity as a likely investment for a mid sized mill.

Market pulp prices are generally in the range of $400-800/ton. Currently the market is low, and prices range between $400-500/ton.. O'Brien reported that Arbokem was producing straw pulp at L250/ton (appox. $400/ton).

If the selling price of pulp was assumed to be $400/ton, all the mills would be profitable immediately under the low cost investment scenario. Profits would increase after the loans were paid off. All the mills would loose money under the high cost estimates, but only until their loans were paid off. The bleach pulp from a new freestanding mill is likely to bring a high price, so initial losses would be less and long-term profits higher.

POTENTIAL INCOME FROM BY-PRODUCTS

Only the Weyerhaeuser estimate above includes any income from potential byproducts. That savings is not carried into the estimates in the tables. Both the Weyerhaeuser study and the Stumborg study in Canada consider the chaff and other organic waste from straw preprocessing as a potentially an income producing by-product. Weyerhaeuser estimates that the feed meal produced from those wastes could net $30-40/ton after processing.

Xiang suggested possibly using mill effluent as a base for an adhesive, but extensive work has to be done to see if it is feasible or economical. Some early British mills produced marketable wax from their straw and grass pulp production. This is possible with certain pulping processes, and should be further explored for its economic feasibility. Xiang, Wong and others have looks at

The figures for total investment need further study. The low pulping cost figures are estimated from figures provided by Universal Pulping, Inc. The costs for pulping equipment and investments internal to the mill are estimated at $20-30 million for each 20,000 tpy of pulp, with 10 year loans at 7% interest and additional expenses included for upkeep. The figures for bleaching costs include costs associated with any required investment in equipment. An additional $10-100/ton is included for transportation of the pulp to a mill (200-2000 miles).

Processing Straw at the Smurfit-Stone Container Corporation Frenchtown Mill

These preliminary estimates for the costs of using straw at the Frenchtown mill are based on incorporating between 20,000-140,000 tons of straw pulp (between 3-20% of the mills output) into its linerboard production. It assumes purchasing straw for between $15-25 and includes baling costs of between $15-25. It also assumes that straw will be transported up to 300 miles, but between 100-200 miles on average, usually in one transportation segment. The average distance would increase as more straw is used. Handling costs are included in the transport estimates.

It is possible that up to 40,000 tpy of pulp may be pulped with existing equipment, although investments would still be required for preprocessing equipment. New pulping equipment would be needed for larger amounts, and possibly for smaller amounts. Some straw would be stored near the mill, but the bulk of the straw would be stored by the growers. Storage would either be under tarps or uncovered. The unbleached pulp produced would be mixed with the wood and recycled pulp already produced at the mill.

Total costs from field through preprocessing are estimated between $80-105/ton. In the high estimate, an additional $5/ton is included for handling pulp and mixing it with existing pulp. The figures for total investment need further study. The costs for pulping and investments internal to the mill have been estimated and include a $5-30 million investment in pulping equipment for each 20,000 tpy of pulp. Loan costs assume 10 year loans at 7% interest and encompasses additional expenses included for upkeep. Pulping costs are based on ranges found in the literature, with the high figures representing very conservative estimates.

Weyerhaeuser Company Project

The costs for the Weyerhaeuser project at their Springfield, Oregon, mill are based on getting rye grass straw from the farmers at no cost. Many growers in the area have traditionally burned their straw, but recently burning has been severely curtailed in the area. Although some growers have taken to plowing the straw under, many feel that that practice could begin to have negative effects on their yields in the moist Willamette Valley. Many growers would welcome someone coming onto their land to bale and remove straw from their fields.

TABLE 2
COMPARATIVE STRAW MILL COSTS: PRELIMINARY MINIMUM ESTIMATE BASED ON 40,000 TPY OF STRAW PRODUCING 20,000 TPY OF PULP

	New Straw Mill	SSCC	Weyerhaeuser
Cost of Straw	$15	$15	$00
Baling	$15	$15	$20
Transport	$15	$30	$15
Preprocessing	$20	$20	$15
Costs to mill	$65	$80	$50
At 50% Yield	$130	$160	$100
Pulping	$15	$15	$15
Bleaching	$30		
Mill Labor	$25	$25	$25
Pulp Transport	$10-75	$00	$10
Loans and upkeep	$200	$50	$50
TOTAL	$410-475	$250	$200
TOTAL LESS INVESTMENT	$210-275	$200	$150

Their study estimates baling costs at $17-24. They generally include three 5-15 mile transport segments: from field to storage, storage to the preprocessing center, and preprocessing to the mill. Some straw would go directly from the field to the preprocessing center. Each transport segment requires two handling phases each costing $2/ton. The short transport segments require $3-5 each.

using potassium and ammonium effluents as fertilizer. This is clearly a possibility, but needs more testing and economic analysis.

ESTIMATES OF TOTAL ECONOMIC EFFECTS OF A NEW MILL

These preliminary estimates are for a 20,000 tpy straw pulp mill using 40,000 tpy of straw. For a larger mill or for more mills of that size, these figures can be multiplied. Ultimately Montana may have the potential for 50 mills of that size, although 10-20 is probably a more realistic figure. Each production unit of that size would require an initial investment of between $5-30 million.

TABLE 4
POTENTIAL STRAW MILL INCOME: BASED ON 40,000 TPY OF STRAW PRODUCING 20,000 TPY OF PULP

PROCESS	INCOME/VALUE
Straw	$600-1000K
Baling	$600-1000K
Transport	$600-2800K
Preprocessing	$800-1000K
Pulping	$300-1000K
Bleaching	$600-1200K
Mill Labor	$500-1000K
Loans and upkeep	$1000-6000K
TOTAL w/ Loans	$5-15 million
TOTAL wo/ Loans	$5-9 million

The total economic activity would be $5-15 million/year while loans were being paid off, and $4-9 million/year after the loans were clear. The economic activities that most directly involve the growers are the sale of straw netting $600,000 to $1 million/year, and the baling of the straw also brings between $600,000 to $1 million/year. Growers might also benefit through income from transporting straw or from investments that they make in the mill.

NEXT STEPS

Many of the next steps were outlined in detail in the section dealing with choosing a pulping process. In reality the steps outlined can be worked on at the same time. There are three priorities at this point:

- Finding potential buyers for the straw pulp and discussing the details of a contracted sales agreement, including the quality and quantity of the pulp they need;

- Inviting more detailed proposals from potential mill designers, including information on the expected quality of the pulp produced and start up costs;

- Finding potential financiers and estimating their available resources.

- After these three steps have been accomplished, a meeting must be set up between the three parties, or two meetings between the potential buyers and the mill designers, and between the mill designers and the financiers.

- Smurfit-Stone needs to be approached as to their willingness to continue investigating the potential for using a percentage of straw in their product and the potential for long-term investment in its use.

- Scouting for potential locations of the mill. At least three specific sites should be located for further study. The sites need reasonably priced land for the mill and storage, easy access to highway and rail transportation, and adequate available water, energy and labor supplies.

- After further meetings and investigation, the number of potential mill designers could be narrowed and a more detailed design and feasibility analysis performed.

Appendix A

BIBLIOGRAPHIES

Following are two bibliographies. The first is a collection of articles and other resources relevant to various aspects of the production and sale of pulp and paper from straw. The second is a collection of articles relevant to the impacts that extended straw removal may have on soil health and erosion. Some articles have tow or more listings from different sources, so that they can be found more easily by researchers.

In the straw pulp and paper bibliography, a few of the articles do not directly discuss straw, but involve a relevant topic. For instances, there is an article cited discussing a bagasse pulping process that may be used on straw. This type of reference was kept to a minimum, to keep the volume of reference to a reasonable level. This bibliography is intended to be as comprehensive as possible, so many citations were taken from footnotes out of available articles and have not been reviewed, since many of the original sources are difficult to find. This bibliography only includes a few of the numerous news articles that simply discuss the possibility or promote the progress of straw pulp and paper production.

In the second bibliography, there are only a few articles that directly discuss the impacts of straw removal on soil health and erosion levels. That is because only a few articles were found directly addressing the topic. The bibliography includes articles on related topic such as tillage practices, above and below ground residues, decay levels, etc.

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Appendix B

POTENTIAL STRAW MILL CONSULTANTS, DESIGNERS AND OPERATORS

The following is a list of various consultants, designers, engineers and companies who could be asked to become in some way involved in a straw pulp mill in Montana. Their potential skills and level of involvement vary, and are described individually along with their contact information below. The list below includes only individuals or companies that have skills to design a mill or a process that is ready for the industrial production of straw pulp. This list in no way claims to be complete and is arranged alphabetically by company.

Arbokem Inc.
Al Wong
P.O. Box 95014
South Vancouver CSC
Vancouver BC V6P 6V4
Phone: 604-322-1317
Fax: 604-322-5865
http://agripulp.com

Mr. Wong has been in the paper industry over 40 years, primarily involved in research and design of pulping systems, for both wood and nonwood pulp. He deserves great credit for his innovation and initiative which, in 1994, led to the opening of the first new straw pulp mill in the US or Canada in over 40 years. Arbokem's pulp mill in Vulcan, Alberta (about an hour south of Calgary) is a small working mill that produces "agripulp" from a potassium based pulping process. The mill has relatively low water consumption, and does not discharge effluent into any lake, river or stream, although there is a small evaporating pond outside of the mill. Mr. Wong claims that the effluent can be used as a fertilizer, although there have still been problems drying it for economical commercial use, and it needs further testing as to its nutritive value.

The pulp from the mill has been used primarily for the production of Arbokem's "Downtown" series of papers that have been produced in a few mills around the country. The Downtown paper is primarily an office or "copy" paper that mixes agripulp with pulp from recycled paper and a chalk filler. Sold at $5/ream it is still 2-3 times as expensive as similar wood papers, but it is more reasonable than many specialty letterheads with high recycled content. It is the most inexpensive office paper with any significant percentage of nonwood fiber. To date, the company has had no problem selling any paper they produced. The company hopes to purchase its own small paper mill to continue production of the Downtown paper series. The pulp has also been used in successful test runs for newsprint, produced at the Smurfit mill in Oregon, (now owned by Smurfit-Stone) and used for major newspapers around the country.

Wong and Arbokem are actively looking for investors to fund a larger mill (approx. 20,000 tpy) to produce more agripulp and Downtown type papers. Wong clearly wants to maintain control of his process and any operation that uses it. Despite my attempts to secure a commitment by the company to get involved in developing a plan for a mill in Montana, Wong has yet to take this initiative seriously and has maintained that he'll respond to requests by individuals or groups who have the investment capital. I still believe that he would respond to either a request for a meeting with some combination of the MGGA, MWBG, or the state of Montana for a proposal to a bid on a small greenfield straw pulp mill.

Crane & Co.
Crane Business Papers
Dalton, MA 01226;
Phone: 800-352-7789

This company is possibly the oldest paper company in the United States, and is best known for their manufacturing of the paper used in the production of US currency. They have extensive experience with producing paper from nonwood fibers. In the last few years they have been diversifying their production to include other nonwood fibers. They now manufacture office letterhead-type paper from hemp, kenaf, recycled US currency, and denim blue jeans.

It is unlikely that Crane would bid on developing a new straw mill, but from my discussions with their representatives, it is clear that they are interested and willing to work to develop and promote nonwood papers. This interest may include providing technical consulting on mill design or production, or the marketing of straw papers. It could also include testing of pulping process and/or nonwood pulps in their paper manufacturing. They could also be a potential buyer from a mill was producing straw pulp, to use it in a blend with their own pulp to improve their papers' smoothness or brightness.

Hurter Consult, Inc.
Robert Hurter
5450 Canotek Rd. No. 51
Ottawa, Ont., K1J 9G3 Canada
Phone: 613-749-2181
Fax: 613-749-1382
E-mail: rhurter@istar.ca.

Hunter Consult has the capability to take a leading role in any or all aspects of building either a free standing straw pulp mill, or a system that would integrate straw into the Smurfit-Stone linerboard mill. They have experience with nonwood fiber plants, and could be of great service doing market studies, feasibility analysis, engineering design and project monitoring. Mr. Hunter has previously chaired the TAPPI Nonwood Plant Fibers Committee, and last year led a successful seminar on Nonwoods at the TAPPI conference, that he expects to re-offer in the coming year, and possibly longer. He has worked in the industry over twenty years had has direct experience and expertise including raw material handling, stock preparation, nonwood pulping, and bleaching. I would highly recommend that Hunter Consult be approached to bid on the design of any straw pulping facility in Montana.

Industra, Inc.
Engineers and Consultants
Hank Bisner, Bill Timmer, Michael Jackson
15055 Sequoia Parkway, Suite 100
Portland, OR 97224
Phone: 503-620-5333

Industra is a moderately large firm and pulp and paper production as one of their primary specialties. They have been looking at producing nonwood pulp from an ammonium sulfite pulping process with an alternative ammonium and potassium chemical, using either a ECF (DEoD) and TCF (OPP) bleaching process. In my interviews with representatives of the company, I did not get the impression that they were ready to take the lead in designing a freestanding straw mill with this or any other process.

They could, however, be of great assistance in either of two capacities: One would be to help in the practical elements of the design of a freestanding mill that incorporated another pulping process design. In a more likely scenario, their consulting services could be valuable in designing and building a straw pulping line that was integrated into the Smurfit-Stone mill in Frenchtown, Montana, incorporating some of their existing energy and water sources, chemical reprocessing and effluent treatment capacities, and fitting the operation into the mill's available spatial requirements.

Jay Jeyasingam
Pulp and Paper Consultant
Longview, WA 98632
Phone: 360-425-4629

Jeyasingam is a consultant who has primarily worked for the UNIDO agency of the United Nations, working to facilitate development of paper production in developing countries. In many cases this means developing nonwood fiber resources, because of the scarcity of wood products in those countries. Jeyasingam has been part of the development or redesign of numerous mills, including straw based mills.

Jeyasingam would be an excellent consultant to work on developing either a freestanding straw pulp mill, or to incorporate a straw pulp production line into the Smurfit-Stone mill in Frenchtown, Montana. Unfortunately, it is unclear as to whether Mr. Jeyasingam would have either the time or inclination to work on this product, or to what capacity.

Joseph A Kurdin
1909 Iowa Drive
Bellingham, Washington
360-671-2778
360-671-2778 (fax)

Mr. Kurdin is currently retired,. In my discussion of this project with him, however, he stated a willingness to work as a consultant on some parts a project to develop a straw-based mill. He spent most of his life in the industry, and has worked on various projects related to nonwood papers, and research on pulping processes that could be used of nonwood fibers, including straw. Mr. Kurdin seemed very disappointed that there is not more work, and more investment by existing paper companies, in nonwood fiber production.

NACO
Michael Jackson
US Contact
Box 169
Tolovana Park, OR 97145
503-436-2110

Naco is interested in licensing its patented process, currently used in an existing successful mill in Italy. It is likely that they could provide extensive technical consulting for a mill using their process. Currently used for the production of corrugated medium, it almost certainly could be used for a pulp mixed in small percentages with other pulps to produce linerboard. See the main body of the text for a description of the Naco process.

SAICA
Manuel Delgado, Managing Director
S.P.T. SA
Av. Normandia 21
28260 Galapagar
Madrid, Spain
Phone: 34-1-859-21-27
Fax: 34-1-859-03-99

As of yet I have not made contact with representative of SAICA, but there are indications in the literature that they may be interested in licensing their process, currently used in an existing successful mill in Spain. Similarly to the NACO process, it is currently used for the production of corrugated medium, but could almost certainly be used for a pulp mixed in small percentages with other pulps to produce linerboard. See the main body of the text for a description of the SAICA process.

Stake Technology Ltd.
2838 Highway 7
Norval Ontario
Canada L0P 1K0
Phone: 905-455-1990

Stake Technology is continuing development on the steam explosion pulping process. They have been in contact with representatives of Smurfit-Stone Container numerous times to discuss the possibility of using their process at the Frenchtown mill. With additional technical consulting, they could design a process line that could be incorporated into the mill there. They believe that the process could be used for a pulp to be mixed in small percentages with other pulps to produce linerboard. See the main body of the text for a description of the steam explosion pulping process.

TEAM Marketing
Tom Shorma
Wahpeton, ND 58074
Phone: 701-642-6026

Mr. Shorma at Team Marketing has worked extensively developing financial and marketing plans for the PrimeBoard operation in Wahpeton, ND, and could do similar work for a straw pulp mill. PrimeBoard produces an MDF type board from straw that is used primarily in the manufacturing of furniture. Many of the elements of the PrimeBoard plant's straw collection, storage and cleaning are potentially similar to that of a straw pulping operation. Mr. Shorma maintains contacts with the PrimeBoard operation, and could possibly arrange consulting help on those elements from PrimeBoard personnel.

Universal Pulping, Inc.
c/o Bill Snyder, Environmental Technologies International
P.O. Box 1158, Eugene, OR 97440
Phone: 541-484-5312
Fax: 541-484-0657
Mr. Snyder works in conjunction with M.V. Byrd of North Carolina State University's Wood and Paper Science Laboratory

(The following is an edited version of their own promotional materials, describing the company and the two pulping processes that Universal Pulping has developed. For a fuller description of the process two-stage process, refer to the pulping section.)

Universal Pulping, Inc. has been formed to commercialize a scale-independent pulping technology that will increase production at conventional mills utilizing traditional feed stocks and provide an economical and effective method to integrate straw and other low cost fibers into existing facilities. UP technology was patented in 1987 following fifteen years of dedicated research and in excess of $1 million invested. UP is currently seeking licensees, partners and collaborators to join in supporting the optimization and commercialization of its technology.

The inventor Eric Prior, has devoted a lifetime conducting research and directing manufacturing in the worldwide pulp & paper industry. Investigations that led to the development of UP was initiated in the mid-1970s to provide pulp for a German waste paper and straw mill producing liners, packaging papers and corrugating medium. Highly restrictive German environmental laws would not permit black liquor disposal as effluent or any air pollution.

The first process can be used either at conventional mills utilizing traditional feed stocks or to provide an economical and effective method to integrate straw and other low cost fibers into existing facilities. This pulping method is a low pressure, low temperature, dilute alkaline/acid hydrolysis technology that allows for the separation of woody materials, cereal straw and other nonwood materials into their three basic components: cellulose, hemicellulose and lignin. The UP process preserves the fiber structure and integrity of wood and nonwood plant fibers such as rye grass and wheat straw. The fiber bundles are not damaged during the gentle cooking process which permits controlled refining, facilitating good drainage, and adding mass to the pulp.

UP's one-stage alkaline process [not described in detail] will yield 80-85%, producing a pulp for unbleached usage such as corrugating medium, newsprint, and liner board. Black liquor from the one stage alkaline process is non-toxic and can become part of the existing recovery system, or recycled with make-up. The initial work comparing the two processes for unbleached pulp determined that UP's single-stage (caustic, low temperature, fast cooking) high yield process was economically preferable to the lower yield two-stage process.

Appendix C

LIST OF POTENTIAL FINANCIERS

In the proposal for this project, the intent was to develop a specific list of possible financiers for a straw pulp mill. During the process of bringing the project together, it became clear that to develop such a list before making a specific recommendation or proposal for the mill's production and pulping process was premature. There are a few specific groups or companies mentioned in the list below, but generally, in lieu of specific financiers, the list below describes the types of groups, organizations and companies where some financing may be available for a straw pulp mill venture.

AGRICULTURAL COOPERATIVES

Cooperatives, largely owned and controlled by the farmers producing the straw, are perhaps the most sensible and likely source of funding for this venture. While farmers are certainly in line to increase their income from any venture that purchases and uses their straw, they could potentially make much more if they invest in the production of a value added product from the straw.

It is one thing to sell straw for $15-25/ton to someone who is willing to bale and haul it from your field, or to bale and haul it to a nearby mill or storage area yourself and make $40-60/ton. It is another to invest in a venture that takes two tons of that straw and makes it into a ton of pulp that sells for $400-800 for a ton of fine paper. With such an investment the farmer could make money on both ends of the venture! The more the farmers put in, the more that they could make, they more control they would have, but of course, they would be taking a bigger risk.

Cooperatives are not simple to start. They come in a variety of forms and they continue to evolve. There are now experts from North Dakota and elsewhere who are clarifying the process can be successful, and proving that they work.

GOVERNMENTAL AGRICULTURAL DEPARTMENTS

There are various governmental organization that provide money for research and investment into new uses for agricultural plants fibers and byproducts, and for value added products. Along with various programs in each state, the biggest is the USDA's Alternative Agriculture Research and Commercialization Corporation (USDA-AARC). Over the last five years, USDA-AARC has made an average of $6.6 million available yearly, with projects averaging $300,000 in venture capital investment. This start-up money is expected to be repaid through equity or sales, and there is usually with an exit strategy involved in the contract with a time frame of 6-8 years. USDA-AARC can be contacted by phone at (202) 690-1633 or their website: www.usda.gov/aarc.

Various state Departments of Agriculture have similar but smaller programs to USDA-AARC. It is likely that this project will be requesting a second year of funding under the Montana Growth Through Agriculture Program. Montanans are not alone in their interest in finding value added products from straw. Both of the Dakotas, and Minnesota have shown clear interest in such projects. It may make sense for these states to form a cooperative venture to develop the first small freestanding mill. Along with the construction costs themselves, there are still significant expenses that will be incurred, even before the mill would get built, for further research and development and to design the mill.

PRIVATE INVESTORS

Private investors are clearly a possible source of funds, and selling shares in the venture is an option that deserves close attention. It is even possible that a significant portion of the capital necessary for a straw mill venture could come from a single or small group of investors.

SPECIALTY PAPER DISTRIBUTORS

Most of the companies that distribute recycled and nonwood papers are small, but there are a few that may be able to secure some funding for a straw mill venture, if they are guaranteed a fixed price or specific share of the product to sell.

PULP AND PAPER AND RELATED COMPANIES

There are a few pulp and paper companies that may be willing to provide a significant amount of capital for a straw mill venture. Considering that they have the only mill in the state, the Smurfit-Stone Container Corporation is an obviously possibility, but there are a number or other companies that could be considered as well.

Smurfit-Stone would clearly have to be involved in any venture that integrated straw pulp production into their Montana mill. Previous to the recent merger with Jefferson Smurfit, Stone Container was undergoing a severe capital crunch, and the merged corporation is still adjusting financially. It is difficult to say how willing that they may be to become involved in this venture.

Still, both Stone and Smurfit had separately looked into using straw in their Montana and Oregon mills. In addition, the Montana mill gets its wood chips as a byproduct from regional sawmills, and these sawmills have gradually been reducing production or closing. In short, the mill's raw material supply is not secure. If this continues, a $20-30 million investment to create a more secure supply of raw material to keep the mill open would be a relatively small investment for a corporation with assets, sales and existing debt each in the billions of dollars.

It is unlikely that they would get involved in providing capital for a freestanding straw pulp mill, but they might still be interested in buying pulp from it if it met their specification and was at a competitive price, and might possibly become involved if they were guaranteed a supply of the straw pulp.

A few other paper companies have recently made various types of commitments to environmentally benign specialty papers. These include Lyons Falls in New York State, Manistique in Michigan, and Crane & Co. in Massachusetts. The Blandin mill in Minnesota has also shown some inclination towards considering straw paper. All of these companies (and possibly others) could be approached to form a partnership for a straw mill venture.

It is possible that other companies may be interested in such a partnership. For instance, Kafus Environmental Industries, Ltd. announced on Earth Day, 1998, that it had raised $270 million to finance the construction of factories to produce high volumes of sustainable, environmentally friendly and structurally superior commodities. They, or a similar company could be a partner, or potentially the lead agent in a straw mill venture.

SOCIALLY RESPONSIBLE INVESTORS

There has recently been significant growth in a phenomenon called socially responsible investment. These investors are looking to invest in companies that are low in pollution, use resources sustainably, and provide jobs with a living wage. Developing relations with these groups could lead to their becoming a significant source of venture capital.

VARIOUS GRAIN ASSOCIATIONS

While they are unlikely to be a significant source of investment capital, various state and national associations such as the National and Montana Grain Growers Associations, the Montana Wheat and Barley Growers and similar organizations could be extremely important to the success of this venture. These associations could provide important contacts with farmers who have investment capital or equity, and provide a information link between the mill developers and the farmers who would be providing straw for the mill or becoming involved as investors.

Appendix D

A PARTIAL LIST OF STRAW MILLS OUTSIDE OF INDIA AND CHINA

As the title suggests this is a partial list of straw-based pulp and paper mills outside of India and China. In China, 90% of paper production is nonwood, predominantly straw produced largely in 6000-10,000 "village" mills. In India there are approximately 90 residue-based mills. Many use straw and most are less than 10,000 tpy. Paavilainen suggests, "There are currently only 11 mills in the world producing 100,000 air dry tons/yr. or more of nonwood pulp." The only proposed mill of any significant size is in Australia, by Arisa Ltd. to be build a mill near Perth. This list should be considered a work in progress, as only partial information has been collected on many of the mills. Since the information on some of these mills is from old sources, it is possible that some have since been shut down.

Country: Spain
Location: Aragón in Zaragoza
Company: Sociedad Anónima Industrias Celulosa Aragonesa
Size: Uses 600 tpd of straw, 120,000 tpy production capacity
Process: SAICA type mill
Product: Corrugated medium (fluting) is made with 20-50% straw provides stiffness.
100% straw pulp is possible for fluting, but hard to run in machines.
One source suggest they had a second mill in El Burgo de Ebro.

Country: Italy
Location: Foggia
Company: Part of the state owned Polygrafico group, Istituto Poligrafico e Zecca della Stato
Size: 35,000 tpy
Process: NACO turbo reactor
Product: Corrugated medium (fluting)
PPI refers to more than one mill in Italy.

Country: Canada
Location: Vulcan, Alberta
Company: Arbokem
Size: Approximately 10,000 tpy
Process: Potassium pulping
Product: Bleached pulp for printing, copy or newsprint

Country: USA
Location: Springfield, Oregon
Company: Weyerhaeuser
Size: The pilot line consumed 60 tpd of preprocessed straw.
Approximately 10,000 tpy production
Process:
Product: Linerboard
This line has been either temporarily or permanently shut down.

Country: Denmark
Location: Hojbygaard?
Company: Fredericia Cellulose
Size:
Process:
Product:
Atchison recognizes this mill as one of the best organized

Country: Romania
Location: Calarasi
Company:
Size: 50,000 tpy
Process: Kraft process
Product:

Country: Romania, built in 1960
Location:
Company: Palas
Size: 15,000 tpy
Process: Soda, first mill to use Pandia digester
Product: Bleached pulp

Country: Mexico, built in 1961
Location: Monterrey
Company: Empaques de Carton Titan
Size: 22,000 tpy
Process: neutral sulphite, wet cleaning of straw, also used Pandia digester
Product: Corrugated medium (fluting)

Country: Hungary, started in 1962
Location: Dunaujvaros
Company: Duna mill, modernized by Sunds in 1987
Size: 30,000 tpy straw (one source suggests that is its supply, another its capacity)
Process:
Product: Produces pulp for printing and writing papers, in a mix up to 50%

Other sources suggest that there is a rice straw mill in Egypt, additional straw mills in Turkey, Greece, France, Yugoslavia and straw mills with Pandia digesters in Germany, Bulgaria, Japan and Algeria.

Appendix E

STRAW PULP AND PAPER CONTACTS

The following is a list of important contact information of people who could be in some way helpful to actualizing a straw pulp mill in Montana. This list includes groups and individuals who are actively or recently been studying straw-paper production potential. These are marked by an astericks.* The list in no way claims to be complete, and not all of the people on the list have been contacted directly during this project, so some information could be outdated. A few are not involved with straw, but are involved producing paper from other nonwood fibers.

Some contacts without names or addresses were kept because they could provide important insights for a developer of a straw mill. Some of the contacts listed are researchers, but this list only includes contact information for a few of the researchers whose papers are listed in the bibliography.

Some on the list have only shown great interest or support for the concept, while others have financial background, development or marketing skills. Still others have engineering or design skills, ideas for new pulping processes, or experience with handling and processing straw or running mills.

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TABLE 5:

MONTANA WHEAT ESTIMATES BY COUNTIES and CROPPING PRACTICES—1990

MONTANA AGRICULTURAL STATISTICS SERVICE

ALL WHEAT 1990

County & Districts	GROSS SEEDED ACRES	NET SEEDED ACRES	HARVESTED FOR GRAIN ACRES	YIELD PER ACRE BUSHELS	PRODUCTION BUSHELS
Deerlodge	1,300	1,300	1,300	53.1	69,000
Flathead	13,200	13,000	12,600	55.5	699,000
Granite	900	900	900	36.7	33,000
Lake	17,900	17,900	17,200	54.7	940,000
Lincoln	0	0	0	0.0	0
Mineral	400	400	400	37.5	15,000
Missoula	4,900	4,900	4,600	37.6	173,000
Powell	1,400	1,400	1,300	36.9	48,000
Ravalli	2,900	2,900	2,700	33.0	89,000
Sanders	3,100	3,100	3,000	42.0	126,000
NORTHWEST	46,000	45,800	44,000	49.8	2,192,000
Blaine	205,100	204,200	195,000	25.4	4,953,000
Chouteau	565,400	563,800	527,000	38.8	20,424,000
Glacier	148,600	147,800	144,500	28.4	4,106,000
Hill	517,700	512,900	504,600	30.7	15,478,000
Liberty	263,800	263,400	256,500	38.0	9,751,000
Phillips	148,200	147,300	135,200	18.7	2,525,000
Pondera	209,600	208,300	205,200	42.5	8,711,000
Teton	176,100	174,900	171,000	40.0	6,837,000
Toole	250,300	250,300	246,000	32.4	7,970,000
NORTH CENTRAL	2,484,800	2,472,900	2,385,000	33.9	80,755,000
Daniels	208,600	208,500	177,900	12.0	2,139,000
Dawson	159,000	156,800	139,000	18.9	2,623,000
Garfield	122,100	121,400	105,100	26.1	2,745,000
McCone	218,700	215,100	165,500	15.6	2,587,000
Richland	167,100	164,900	126,000	19.7	2,479,000
Roosevelt	326,500	322,400	229,000	12.7	2,902,000
Sheridan	279,500	278,100	261,000	15.5	4,052,000
Valley	303,500	302,200	245,500	12.8	3,151,000
NORTHEAST	1,785,000	1,769,400	1,449,000	15.7	22,678,000
Broadwater	46,100	46,100	44,100	30.8	1,359,000
Cascade	161,800	159,300	135,800	34.2	4,641,000
Fergus	187,100	182,300	176,100	36.8	6,480,000
Golden Valley	52,000	52,000	47,000	25.8	1,212,000
Judith Basin	94,000	94,000	90,000	27.8	2,506,000
Lewis & Clark	19,000	18,200	18,000	39.0	702,000
Meagher	12,500	12,500	11,000	23.0	253,000
Musselshell	35,000	35,000	29,000	29.1	843,000
Petroleum	24,500	24,500	23,000	26.4	608,000
Wheatland	45,000	43,500	42,000	22.3	936,000
CENTRAL	677,000	667,400	616,000	31.7	19,540,000
Beaverhead	9,300	9,300	8,300	38.1	316,000
Gallatin	48,300	48,200	46,900	47.6	2,234,000
Jefferson	4,500	4,500	4,500	20.4	92,000
Madison	10,700	10,700	10,100	30.3	306,000
Silver Bow	400	400	400	22.5	9,000
SOUTHWEST	73,200	73,100	70,200	42.1	2,957,000
Big Horn	143,800	143,700	140,600	34.4	4,839,600
Carbon	19,700	19,700	19,100	31.4	598,800
Park	14,600	14,600	14,100	35.3	497,600
Stillwater	56,600	56,600	54,500	28.0	1,527,000
Sweetgrass	5,500	5,400	5,000	26.0	130,000
Treasure	6,000	6,000	6,000	51.7	310,000
Yellowstone	101,100	101,100	96,000	30.7	2,949,000
SOUTH CENTRAL	347,300	347,100	335,300	32.4	10,852,000
Carter	42,000	40,300	37,000	19.8	734,000
Custer	48,500	48,500	46,000	21.5	991,000
Fallon	54,500	54,000	47,000	16.8	791,000
Powder River	31,500	31,200	29,000	30.6	887,000
Prairie	41,000	41,000	35,000	28.4	995,000
Rosebud	56,100	56,100	52,100	31.0	1,614,000
Wibaux	58,100	57,200	39,400	22.3	879,000
SOUTHEAST	331,700	328,300	285,500	24.1	6,891,000
MONTANA	5,745,000	5,704,000	5,185,000	28.1	145,865,000

TABLE 6:

QUESTION 1: **How many acres of the following crops did you harvest in the past four years?**

Respondents indicating acreages for wheat and barley for the various years are as follows:

1996	Wheat	256	1995	Wheat	256
	Barley	174		Barley	174
1994	Wheat	252	1993	Wheat	247
	Barley	173		Barley	174

Total acreages for the period are as follows:

1996	Wheat	427,406	1995	Wheat	393,650
	Barley	80,842		Barley	78,683
	Total	508,248		Total	472,333
1994	Wheat	389,487	1993	Wheat	379,584
	Barley	77,784		Barley	76,534
	Total	467,271		Total	456,534

The average number of acres per respondent are as follows:

1996	Wheat	1,670	1995	Wheat	1,538
	Barley	464		Barley	452
	Total	1,904		Total	1,769
1994	Wheat	1,546	1993	Wheat	1,537
	Barley	450		Barley	440
	Total	1,750		Total	1,708

Barley acreage averaged approximately 20% of the wheat acreage. The average acreage per farmer for both wheat and barley over the four year period was 1,783 acres.

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TABLE 7:

THE WORLD'S TOP 20 PRODUCING AND CONSUMING COUNTRIES

Estimates and Forecasts (1,000 tonnes)

Paper & Board Production	PPI 1994e	FAO 1998e	Pulp Production	PPI 1994e	Paper & Board Consumption	PPI 1994e
1. USA	79,770	88,591	1. USA	58,060	1. USA	84,184
2. Japan	28.417	35,871	2. Canada	22,900	2. Japan	28,650
3. China	18,120	23,355	3. China	16,055	3. China	20,330
4. Canada	16,620	19,873	4. Japan	10,540	4. Germany	16,500
5. Germany	14,250	17,561	5. Sweden	10,351	5. UK	9,754
6. Finland	11,000	12,513	6. Finland	9,750	6. France	9,465
7. Sweden	9,264	10,346	7. Russia	n/a	7. Italy	8,100
8. France	8,490	11,050	8. Brazil	5,745	8. Russia	5,935
9. Italy	6,600	6,960	9. France	2,740	9. Korea	5,800
10. Korea	6,150	7,962	10. Norway	2,290	10. Canada	5,365
11. Russia	6,000	12,470	11. South Africa	2,205	11. Spain	4,885
12. UK	5,700	6,425	12. Germany	1,900	12. Taiwan	4,630
13. Brazil	5,566	7,351	13. Chile	1,600	13. Brazil	4,181
14. Taiwan	4,200	n/a	14. India	1,600	14. Mexico	3,670
15. Spain	3,550	4,403	15. Austria	1,580	15. Australia	3,013
16. Netherlands	2,950	3,243	16. Portugal	1,560	16. India	2,808
17. Indonesia	2,850	4,012	17. Indonesia	1,498	17. Sweden	2,264
18. Mexico	2,840	4,295	18. New Zealand	1,402	18. Belgium	2,177
19. India	2,540	4,936	19. Spain	1,380	19. Thailand	1,786
20. Norway	2,040	2,590	20. Poland	900	20. South Africa	1,555

COMPILED BY AIKMAN

TABLE 8:

WORLD PAPERMAKING PULP CAPACITY 1975-1998

	TOTAL CAPACITY (million tonnes)				ANNUAL INCREASE (%)	
	1975	1988	1993	1998E	88-98E	93-98E
TOTAL PULP CAPACITY	136.1	175	197	208	2.5%	1.1%
TOTAL WOOD PULP	126.8	160	176	185	2.0%	1.0%
TOTAL NON-WOOD	9.3	15	21	23	6.0%	2.5%
NON-WOOD (%)	6.9	8.6	10.6	11.0		

[Source: United Nations Food and Agriculture Organisation - Capacity Survey
Atchinson's Consultants Inc.]

COMPILED BY AIKMAN

TABLE 9:

ESTIMATED AVAILABILITY OF SPECIFIC NON-WOOD PLANT FIBROUS RAW MATERIALS - 1993 (1,000 bone-dry tonnes)

	WORLD	EU12	USA
Sugar cane bagasse	83,000	n/a	4,260
Straws			
Wheat	545,000	45,573	72,000
Barley straw	175,000	25,372	6,000
Oat straw	60,000	3,540	10,000
Rye straw	40,000	3,740	800
Rice straw	350,000	852	2,500
Seed flax straw	2,000	118	500
Grass seed straw	3,000		1,000
Sub-total straw	1,175,000	79,195	92,800
Stem fibre, including jute, kenaf, hemp, etc. (whole stalk) of which is bast fibre (3,000)	13,700	n/a	
Leaf fibre, including sisal, henequen and maguey	500		
Abaca or manila hemp	81		
Reeds (estimated)	30,000		
Bamboo (estimated)	30,000		
Papyrus (estimated)	5,000		
Esparto grass (estimated)	500		
Sabai grass	200		
Total cotton staple fibre	18,300		3,100
Total first and second cut linters	2,724		460
Cotton stalks	68,000		4,600
Corn stalks	690,000	28,031	129,000
Sorghum stalks	242,000	939	28,000
Hemp fibre and tow	218	n/a	
Total Estimated Fibres	**3,534,223**	**108,165**	**355,020**

n/a - figures not available

[Sources: FAO Capacity Survey - Worldwide & USA
EU12 - based on European Commission Crop Production Statistics & Atchinson Consultants calculations on crop yields on raw material]

COMPILED BY AIKMAN

TABLE 10:

NON-WOOD PULP CAPACITY FOR LEADING COUNTRIES (1000 tonnes)

	1985	World %	1990	World %	1995E	World %
TOTAL NON-WOOD						
China	6,775	50.7	9,718	62.4	13,630	65.9
India	1,830	13.7	1,330	8.5	1,858	9.0
Indonesia	262	1.0	477	3.1	477	2.3
CIS	625	4.7	390	2.5	390	1.9
USA	321	2.4	299	1.9	327	1.6
Other 19 countries	2,843	22.3	2,693	17.4	3,302	16.0
Estimated total for 52 countries	13.352	100.0	15,562	100.0	20,666	100.0
STRAW PULP						
China	5,037	81.7	5,831	85.9	8,178	87.9
India	350	5.7	200	2.9	230	2.5
Spain	115	1.9	138	2.0	144	1.6
Other 16 countries	622	10.5	586	8.6	744	7.9
Estimated total for all countries	6,166	100.0	6,787	100.0	9,304	100.0
BASASSE PULP						
India	30	1.3	428	15.5	928	25.4
China	351	15.0	391	14.2	548	15.0
Mexico	408	17.4	303	11.1	305	8.4
Other 20 countries	1,550	66.3	1,617	59.2	1,868	51.2
Total for 23 countries	2,339	100.0	2,739	100.0	3.649	100.0
BAMBOO PULP						
India	1,200	77.7	572	57.9	572	47.6
China	1,175	11.3	166	16.8	233	19.4
Thailand	8	0.5	60	6.1	200	16.7
Other 6 countries	162	10.5	189	19.2	196	16.3
Total of 9 countries	1,545	100.0	987	100.0	1,201	100.0
Miscellaneous Pulp						
China	1,212	36.8	3,330	66.0	4,671	71.7
CIS	625	19.0	390	7.7	390	6.0
USA	321	9.7	239	4.7	267	4.0
India	250	7.6	128	2.5	128	2.0
Estimated total of all countries	3,302	100.0	5,049	100.0	6,512	100.0

[Source : FAO Capacity Survey]

COMPILED BY AIKMAN

TABLE 11:

LEADING COUNTRIES IN STRAW PULPING CAPACITY IN 1985 and 1993, WITH ESTIMATES FOR 1998 AND PERCENTAGES OF WORLD TOTAL CAPACITY FOR EACH COUNTRY

	1985		1993		1998 ESTIMATES	
COUNTRY	CAPACITY 1000 MT	% OF WORLD TOTAL	CAPACITY 1000 MT	% OF WORLD TOTAL	CAPACITY 1000 MT	% WOR TOTA
1. China	5037	81.7	8413	87.95	9015	88.49
2. INDIA	350	5.7	284	2.97	296	2.9
3. SPAIN	115	1.9	125	1.31	125	1.2
4. ITALY	92	1.5	30	0.31	30	0.2
5. TURKEY	77	1.2	77	0.80	77	0.76
6. DENMARK	70	1.1	51	0.54	51	0.5
7. EGYPT	67	1.1	67	0.70	67	0.6
8. ROMANIA	58	0.9	58	0.60	58	0.57
9. GREECE	50	0.8	10	0.10	15	0.1
10. INDONESIA	43	0.7	52	0.54	52	0.5
11. PAKISTAN	33	0.5	260	2.72	260	2.55
12. SYRIA	32	0.5	0	0	0	0
13. BULGARIA	28	0.5	12	0.12	12	0.1
14. YUGOSLAVIA	28	0.5	28	0.29	28	0.2
15. ALGERIA	25	0.4	25	0.26	25	0.25
16. HUNGARY	19	0.3	7	0.07	7	0.0
17. SRI LANKA	16	0.3	9	0.09	9	0.0
18. THAILAND	12	0.2	10	0.10	10	0.10
19. IRAN	0	0	30	0.31	30	0.2
Sub-Total 1st. 19 COUNTRIES	6152	99.8	9548	99.81	10,167	99.
ESTIMATED TOTAL FROM ALL COUNTRIES PRODUCING STRAW PULP	6166	100	9566	100.0	10,187	100.

SOURCES: DATA BASED ON FAO CAPACITY SURVEYS AND INFORMATION OBTAINED FROM INDIVIDUAL COUNTRIES BY:

JOSEPH E. ATCHISON CONSULTANTS, INC.

TABLE 12:

PHYSICAL AND CHEMICAL CHARACTERISTICS OF DIFFERENT FIBRES

	Pine	Eucalyptus	Straw	Bagasse	Bamboo	Hemp	Kenaf
Fibre Length (mm)	4.0	1.4	1.2-1.5	1.2-1.5	2.9-4.0	0.7-55	3
Cellulose (%)	42	46	33-40	40-43	50	45-72	
Hemicellulose (%)	25	27	24-28	30-32	16-21	7.7-17.8	
Lignin (%)	28	26	10-17	24	24	2-20	9-18
Silica (%)	0.03 - 0.1	0.03 - 0.1	3	1.5-4.0	24	1.5-3.5	0-0.03
Ash (%)	1	1	4-7	3-8	4-7		2.2-6.2

[Source : IIED]

COMPILED BY AIKMAN

TABLE 13:

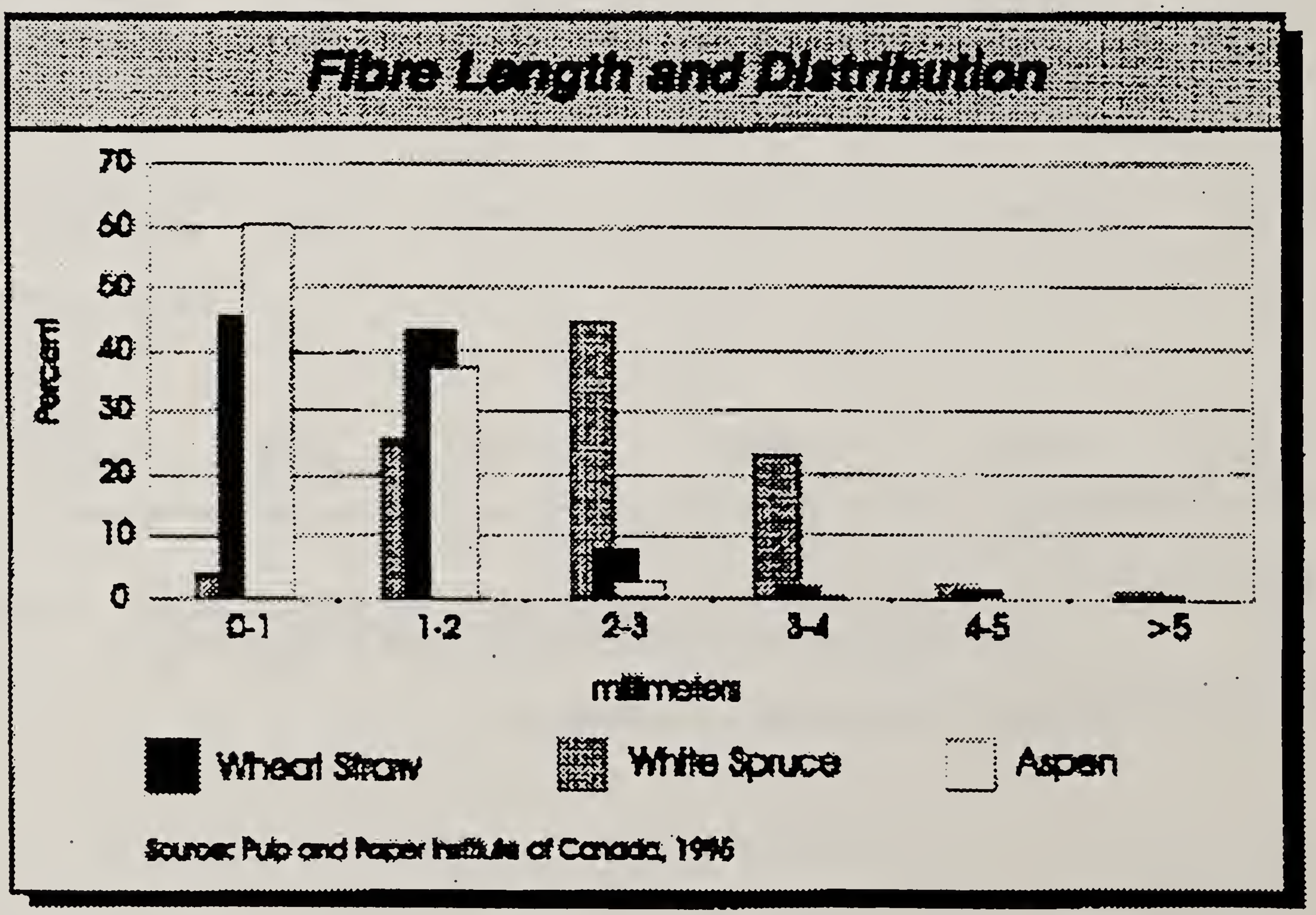
Procurement Cost for Wheat Straw in Western Canada

	$/tonne
Baling	11.65
Loading	2.65
Hauling [†]	9.20
Nutrient loss to the producer	4.80
Break even (FOB pulping plant)	**28.30**

Source: Cochrane Group, 1994

[†] Based on 50 km haul

FIGURE 1:

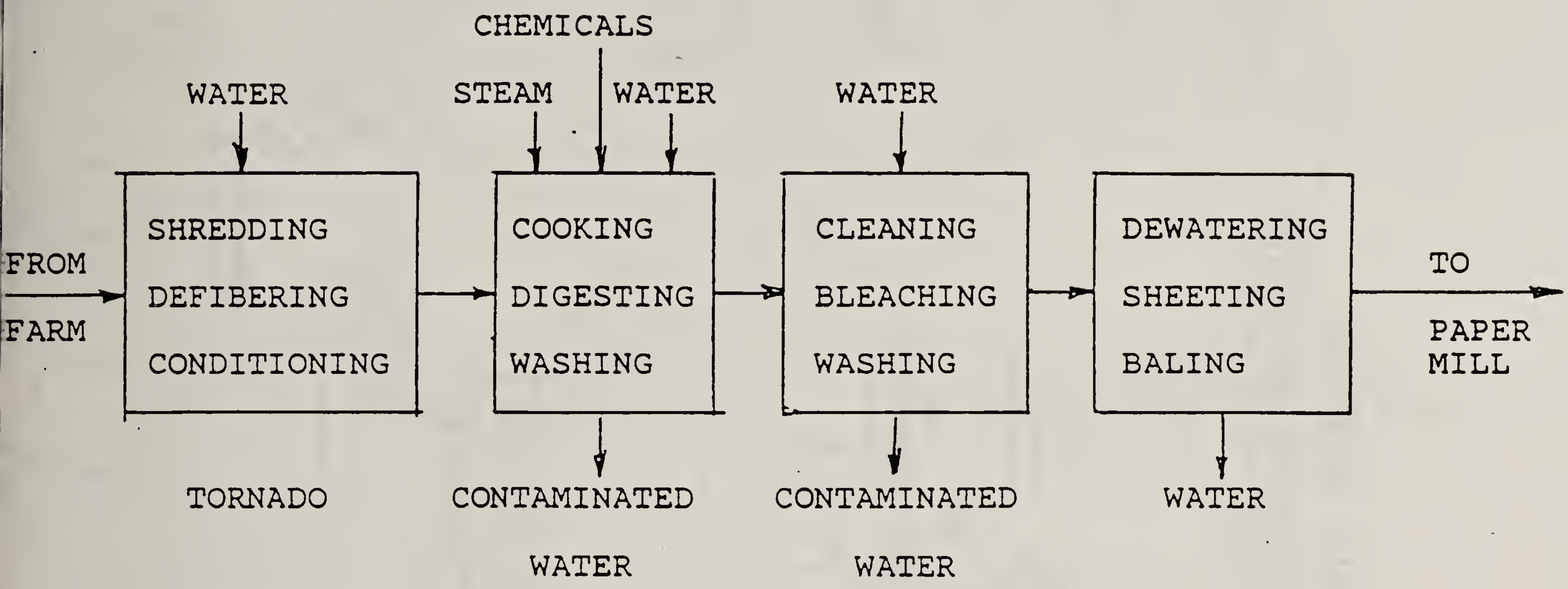


Fibre Length and Distribution

Source: Pulp and Paper Institute of Canada, 1996

FIGURE 2:

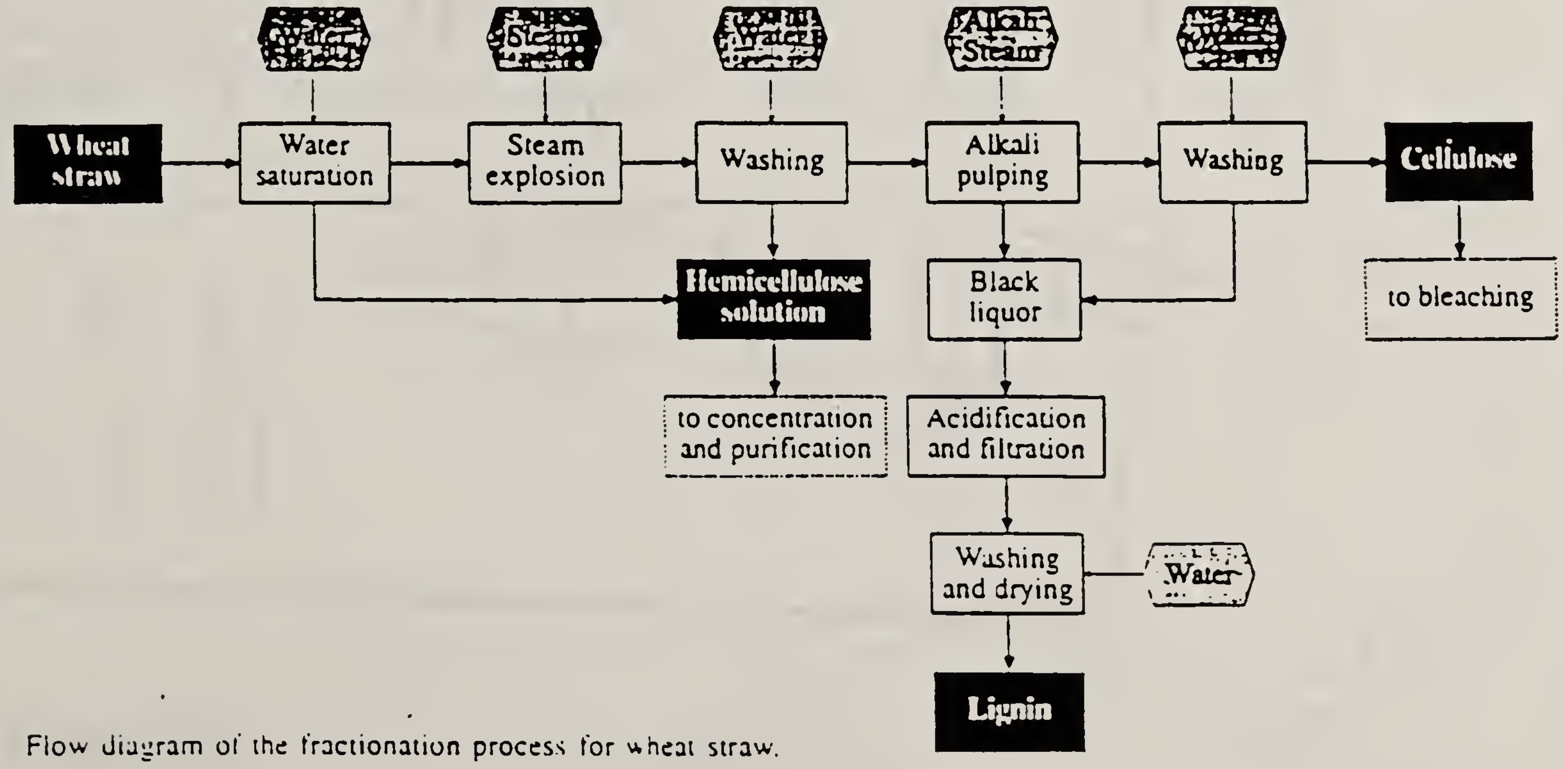
FROM PLANT MATERIAL TO PULP



SOURCE: HURTER

FIGURE 3:

D. Montané *et al.*: Alkali Delignification of Steamed Straw



Flow diagram of the fractionation process for wheat straw.

FIGURE 4:

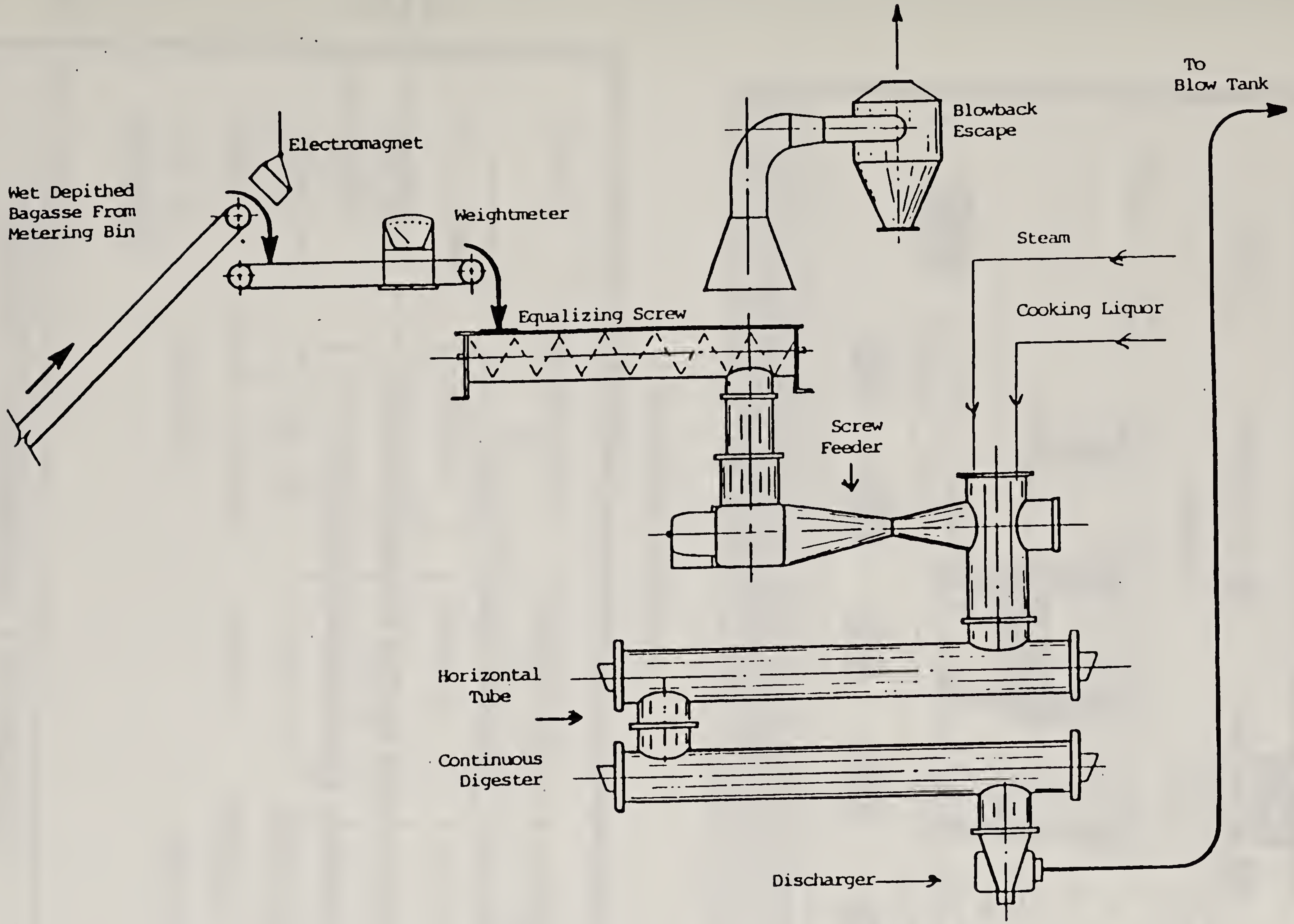


FIGURE 1: RAPID COOKING HORIZONTAL TUBE DIGESTER SYSTEM FOR PULPING BAGASSE AND OTHER NON-WOOD PLANT FIBERS

SOURCE: ATCHISON

FIGURE 5:

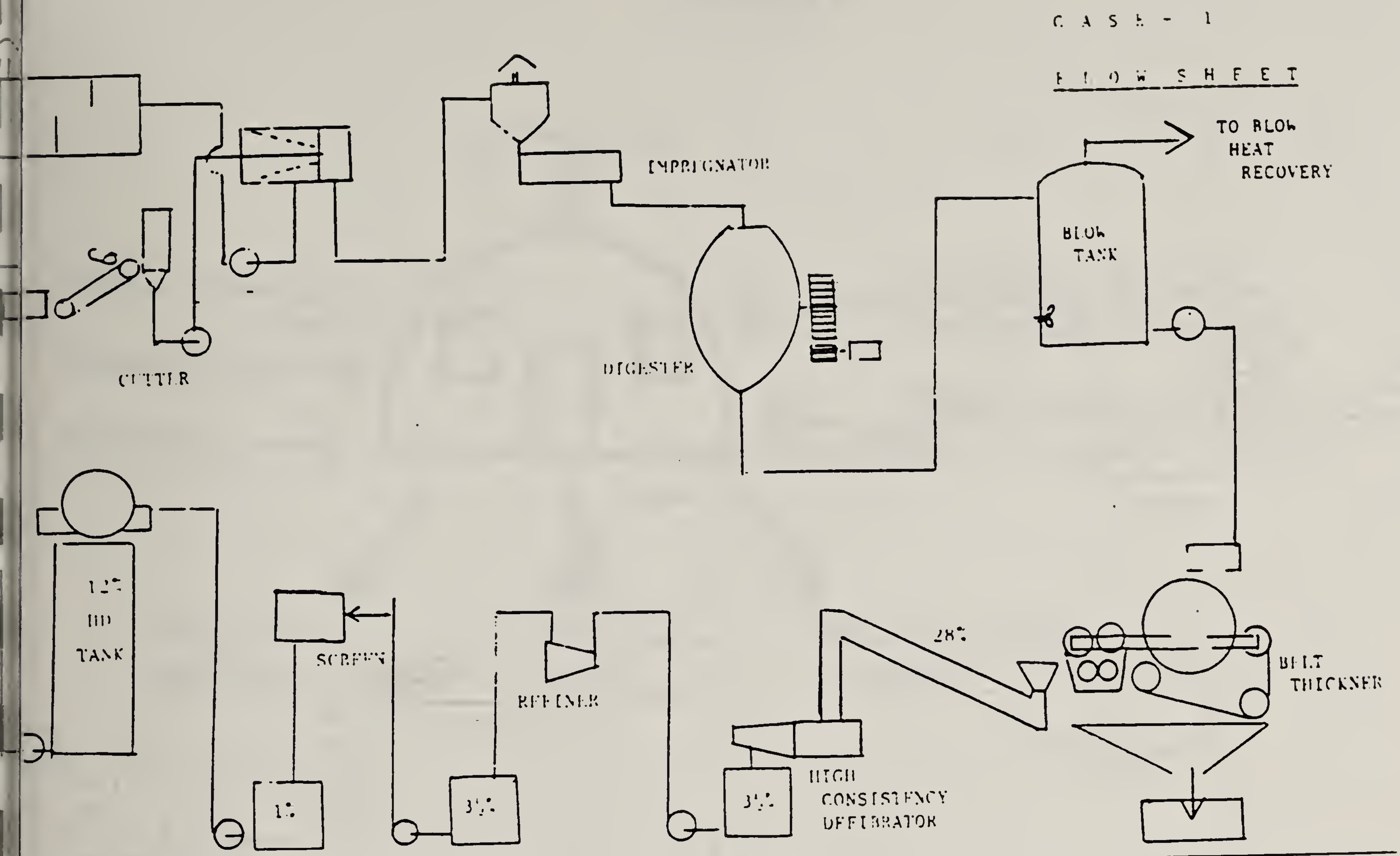
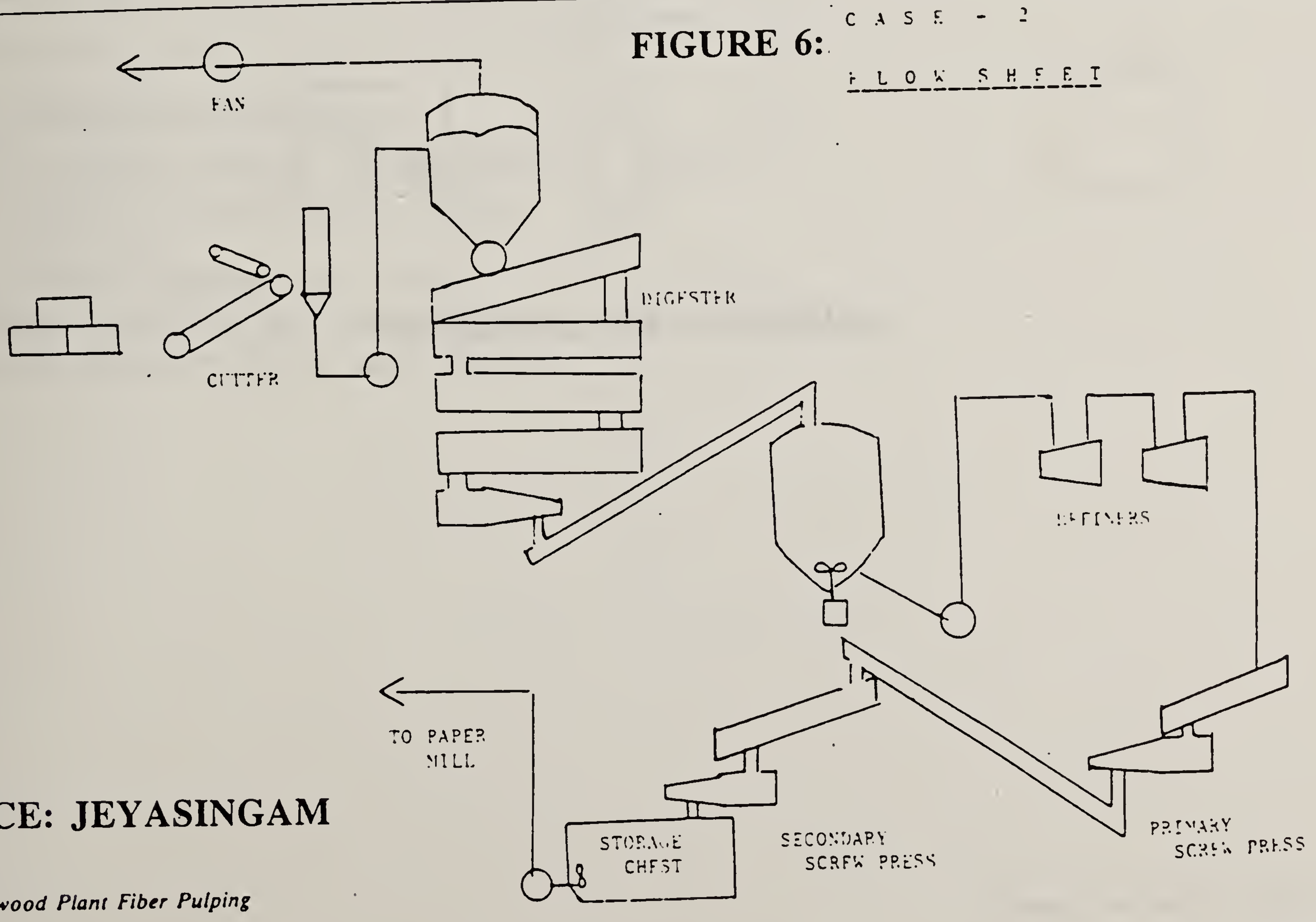
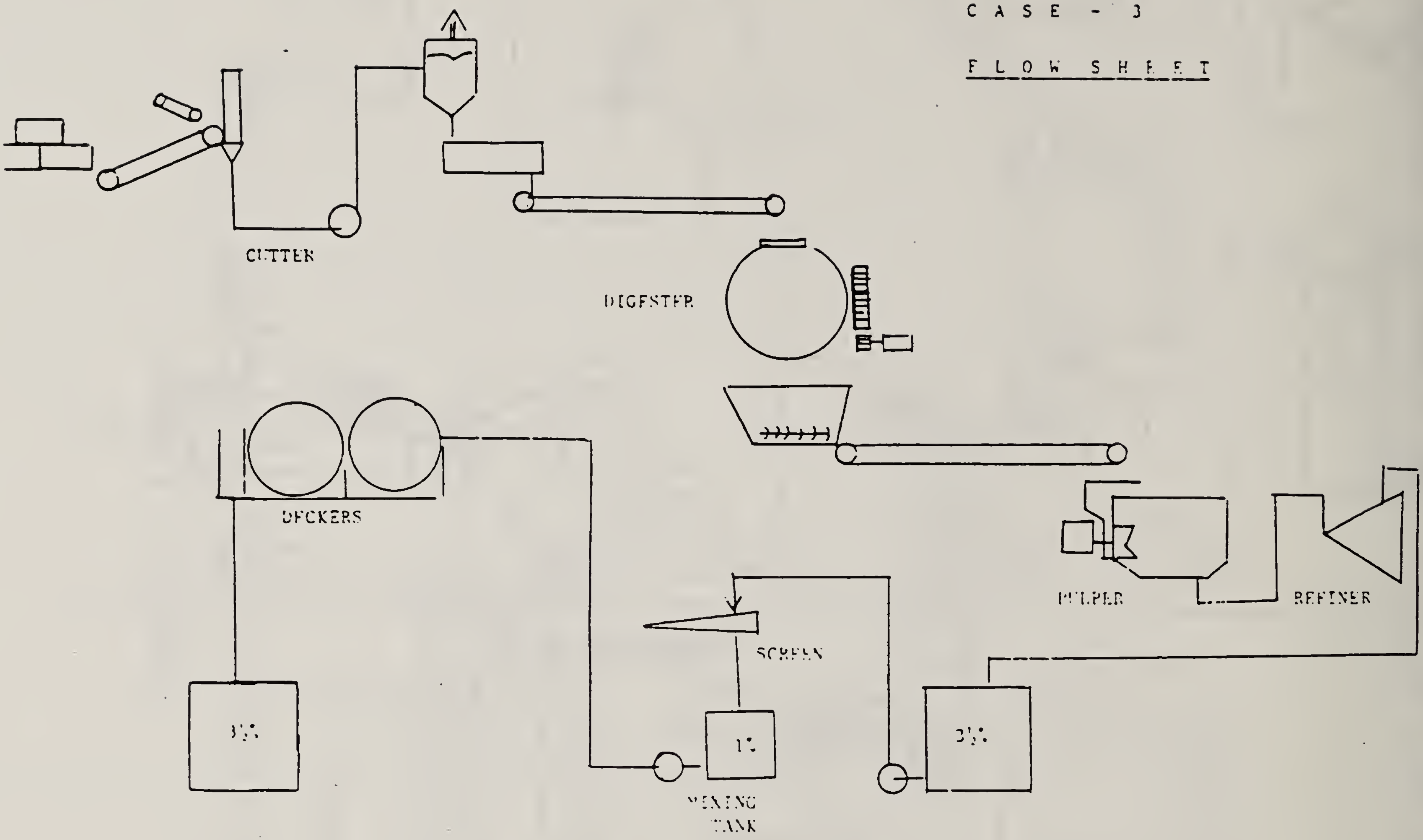


FIGURE 6:



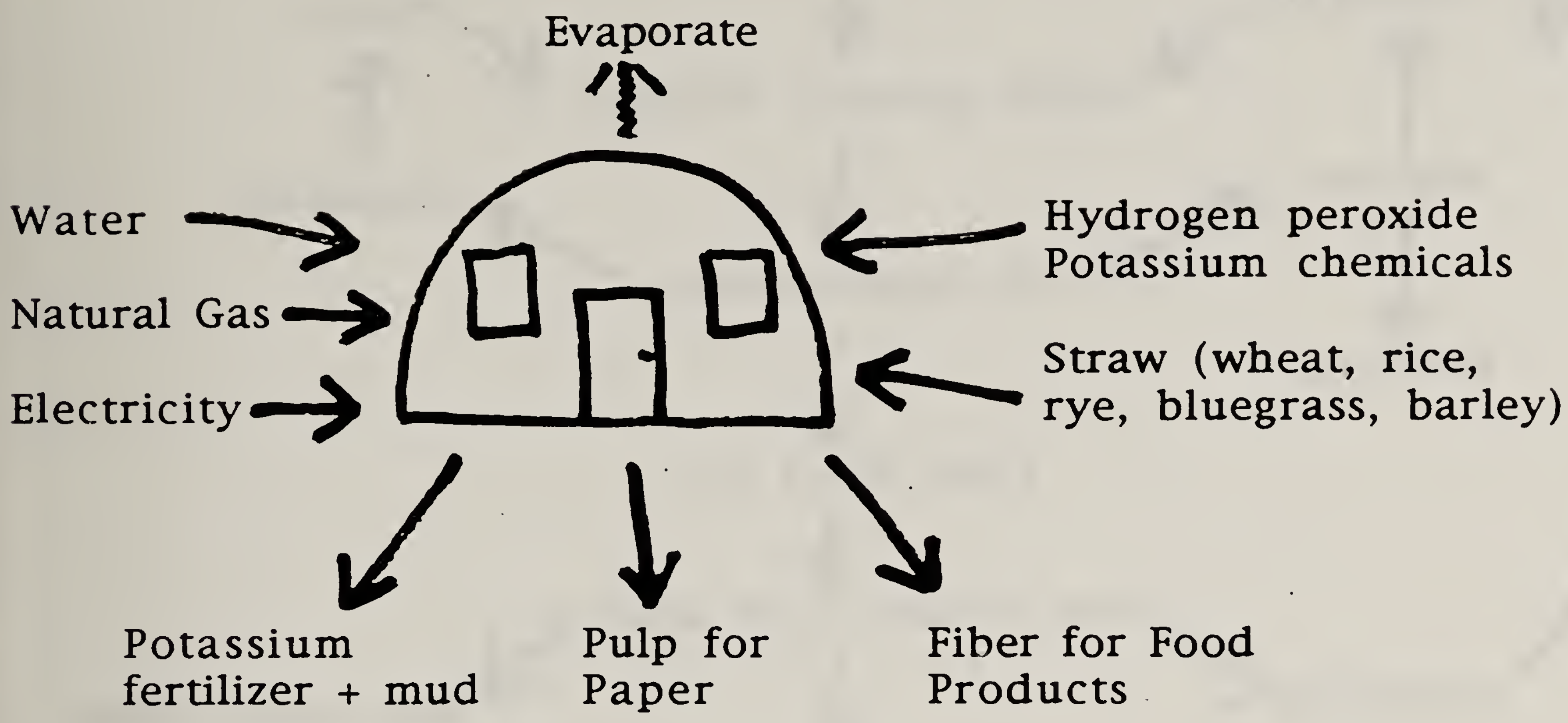
SOURCE: JEYASINGAM

FIGURE 7:



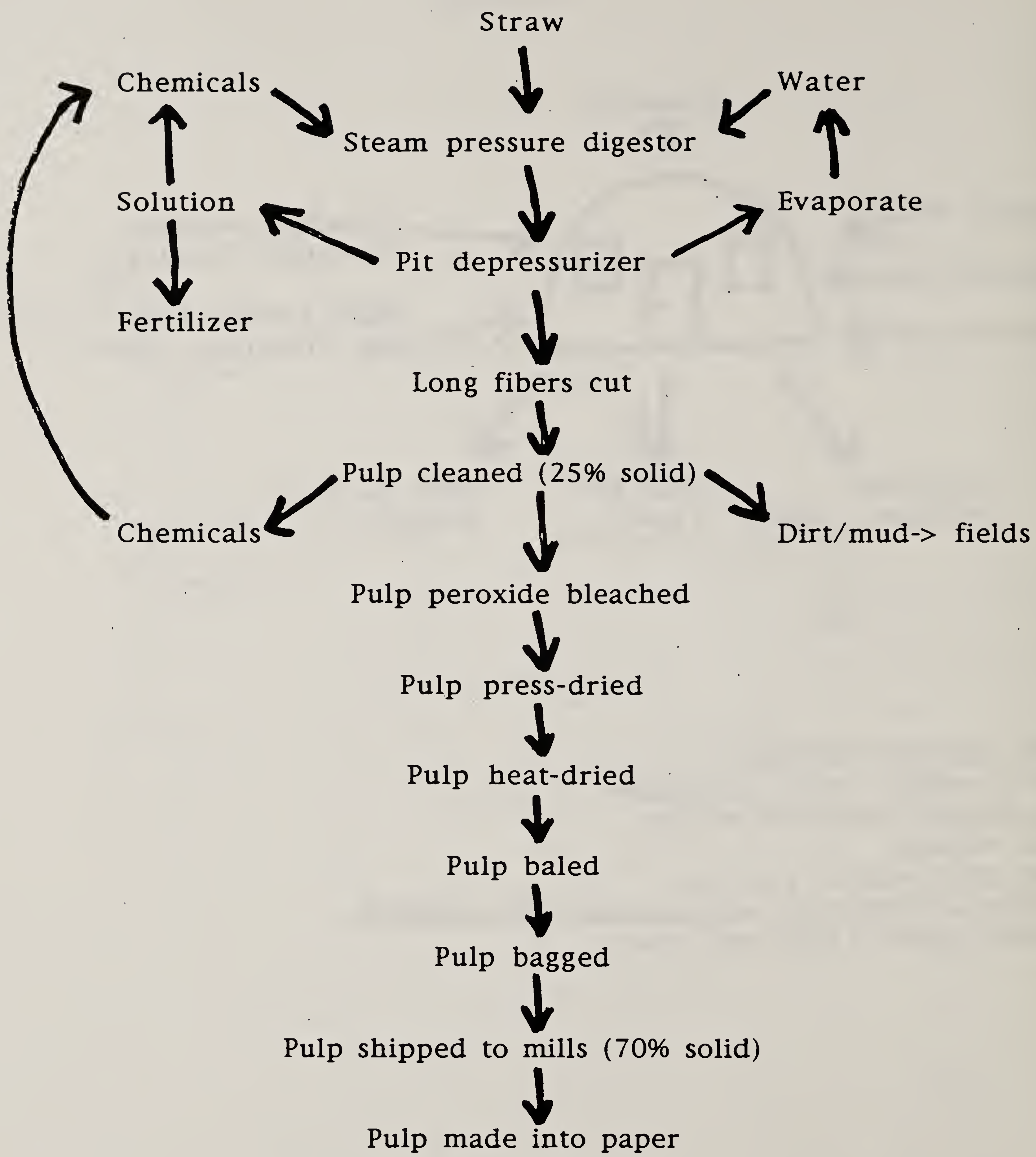
SOURCE: JEYASINGAM

FIGURE 8:



THE ARBOKEM PROCESS:
25-30 million dollar investment
No chlorine chemicals or acids
Zero effluent
Uses crop residue, not trees
Creates a market for nuisance and waste material
Creates close to forty new jobs.

FIGURE 9:


Straw
Chemicals
Water
Steam pressure digestor
Solution
Evaporate
Pit depressurizer
Fertilizer
Long fibers cut
Pulp cleaned (25% solid)
Chemicals
Dirt/mud-> fields
Pulp peroxide bleached
Pulp press-dried
Pulp heat-dried
Pulp baled
Pulp bagged
Pulp shipped to mills (70% solid)
Pulp made into paper